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AN UPGRADED VERSION OF THE NUCLEON MESON TRANSPORT CODE: NMTC/JAERI97

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An Upgraded Version of the Nucleon Meson Transport Code : NMTC/JAERI97

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The nucleon-meson transport code NMTC/JAERI is upgraded to NMTC/JAERI97 which has new features not only in physics model and nuclear data but also in computational procedure. NMTC/JAERI97 implements the following two new physics models : an intranuclear cascade model taking account of the in-medium nuclear effects and the preequilibrium calculation model based on the exciton one. For treating the nucleon transport process more accurately, the nucleon-nucleus cross sections are revised to those derived by the systematics of Pearlstein. Moreover, the level density parameter derived by Ignatyuk is included as a new option for particle evaporation calculation.

Other than those physical aspects, a new geometry package based on the Combinatorial Geometry with multi-array system and the importance sampling technique are implemented in the code. Tally function is also employed for obtaining such physical quantities as neutron energy spectra, heat deposition and nuclide yield without editing a history file. The resultant NMTC/JAERI97 is tuned to be executed on the UNIX system.

This paper explains about the function, physics models and geometry model adopted in NMTC/JAERI97 and guides how to use the code.

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核子・中間子輸送コードの改良版NMTC/JAERI97

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これまで用いてきた核子・中間子輸送コードNMTC/JAERIについて物理モデル、核データだけでなく計算手法に改良を加えてNMTC/JAERI97を完成させた。NMTC/JAERI97は以下の新しい物理モデルを装備している。即ち、原子核媒質効果を考慮する核内カスケードモデルと励起子モデルに基づく前平衡計算モデルである。核子輸送過程をより正確に取り扱うために、核子・原子核断面積はPearlsteinの系統式による断面積に変更した。また、粒子蒸発計算のためにIgnatyukによる準位密度パラメータを新規のオプションとして取り入れた。

これらの物理的側面のほかに、多重配列システムを用いた結合型幾何形状とインポータンスサンプリング手法をコードに組み込んだ。中性子エネルギースペクトル、発熱量及び核種生成率等の物理量をヒストリーファイルを編集することなく求めるために、タリー機能も導入した。作成したNMTC/JAERI97コードはUNIX上で実行できるようにチューニングされている。

本レポートではNMTC/JAERI97の機能、物理モデル及び幾何形状モデルについて解説し、コードの使用法についても説明する。

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1. Introduction

The nucleon meson transport code NMTC/JAERI[1] was developed in 1982 from its original version of NMTC[2] by Nakahara and Tsutsui for studying nuclear spallation reactions and particle transport in a medium. The code can simulate both the primary spallation reaction and the secondary particle transport in the intermediate energy region from 20 MeV to 3.5 GeV by the use of the Monte Carlo technique. The code has been employed in combination with the neutron-photon transport codes available to the energy region below 20 MeV for neutronics calculation of accelerator-based subcritical reactors, analyses of thick target spallation experiments and so on.

With recent progress in theoretical and experimental studies of nuclear physics, it turned out clear through the international code intercomparison[3,4] that physical models and nuclear data employed in the code should be upgraded to improve its own simulation accuracy. Nuclear reactions have been simulated by the intranuclear-cascade[5] evaporation[6] model including high energy fission process[7] in NMTC/JAERI so far. The following models and data were upgraded in this work : a preequilibrium reaction calculation model based on the closed form exciton model, level density parameter dependent on an excitation energy of a residual nucleus for estimating particle emission from evaporation process, an alternative intranuclear cascade model in which nuclear medium effects are taken into account in terms of reflection and refraction with in-medium nucleon-nucleon collision cross sections. For particle transport calculation, moreover, nucleon-nucleus collision cross sections were replaced with the values obtained by the systematics derived by Pearlstein[8] from the geometrical cross section of a target nucleus.

In the upgraded version, a new geometry package based on the combinatorial geometry (CG) method, MARS[9,10], was implemented for describing complex configurations such as a target-moderator-reflector system for intense spallation neutron source. Since the NMTC /JAERI employs the Monte Carlo technique, all of event information can be stored in a history file. Nuclear characteristics such as particle energy spectrum, heat deposition and nuclide yield are calculated from the history file independently using a supplementary program. The history file requires a computer with a large disk volume for simulating particle transport phenomena in a large scale system in detail. In order to save the disk volume and analyze the history file in the main frame of the transport calculation, a utility function with several tallies has been also developed and added to NMTC/JAERI so that the information about the nuclear characteristics could be obtained right after a simulation is finished. In addition, the importance sampling technique was also adopted for variance reduction of the Monte Carlo calculation of large scale system even with a limited number of incident particles.

In the framework of this upgrade, the source program was tuned to be executed on the UNIX system of FUJITSU S-7/300 (OS:Solaris 2.5) installing SPARCompiler FORTRAN 77 Ver. 4.0 and HPUS-9 with an available FORTRAN compiler. This upgraded version of NMTC/JAERI is denoted as "NMTC/JAERI97" in this report. The outline of NMTC/JAERI97 is described in Chapter 2. The models and nuclear data employed in the code are explained in Chapter 3. New functions of MARS, importance sampling technique and tally functions are introduced in Chapters 4 to 6. Chapter 7 is devoted to the user guide for installation of code, preparation of the input data, execution of the calculation and the formatting of output files. A relevant program, examples of input and output files, and the drawings for making a geometry data are described in the Appendices.

2. Overview of the Code

NMTC/JAERI97 simulates the transport of the particles of proton, neutron, pions and muons using the Monte Carlo technique. The random number generator on the basis of the congruential scheme of Lehmer[11], which is the same as for the MCNP4A [12] code, is employed for the Monte Carlo calculation. The user is able to change the initial value of random number by the input data. For the transport calculation, the maximum energy is limited to 3.5 GeV for nucleon and 2.5 GeV for pions. It is noted that the maximum incident energy comes down to less than 1.0 GeV when the ISOBAR code is used for the intranuclear cascade calculation. Allowable mass range of target nucleus is A=1 and 6 $\leq A \leq$ 250. Though the light particles of deuteron, triton, helium-3 and α-particle are produced in the preequilibrium and the evaporation process, the transport of these particles is not treated. The production of γ-ray is not taken into account, neither. The code calculates particle energy spectra, heat deposition and nuclide production in a medium in the energy region above cut-off energy. In general, the cut-off energy is set at a few MeV for charged particles and 20 MeV for neutron. The transport of neutrons with energies below 20 MeV is calculated by the neutron-photon transport code such as MCNP4A using a cross section library processed from evaluated nuclear data. Figure 1 shows the flow of neutronics calculation with the NMTC/JAERI97 and the MCNP4A code. A user-supplied source routine is required to read the information of the cut-off neutrons for the MCNP4A calculation. The input data must be prepared independently for MCNP4A according to its input manner[12].

The source routines of NMTC/JAERI97 can be classified into several packages according to their function.

(1) Geometry Package

The extended version of Combinatorial Geometry (CG) package, MARS (Multiple Array System)[9,10], is included in NMTC/JAERI97 for defining a geometry model of a problem and recognizing the position of particles in a system. Figure 2 shows the calculation flow for checking the position of a travelling particle in the system. MARS has new features of "array" and "universe" that can describe the lattice geometry of CG efficiently and quickly with the minimum of geometry approximations. The input manner for geometry model description is basically the same as that for ordinary CG except the part for forming the array and universe. The geometry model description manner is explained in detail in Chapter 4.

(2) Source Particle Configuration

The geometrical configuration of an incident beam is specified in the subroutine "SORS". The circular, right rectangular and Gaussian configurations can be treated as the surface source. This subroutine can also produce the volume sources with the cylindrical, right rectangular and Gaussian configurations. The energy distribution of the source particle can be assigned arbitrary in the present version if necessary. The direction of an incident particle, however, is limited to either positive or negative direction on the z-axis. An instruction how to give the geometry of incident beam is described in the input cards 22 to 23 (see Section 7.2).

(3) Macroscopic Transport Calculation Package

The macroscopic transport of particles are calculated in the subroutine "OVLY12" which is composed of many subroutines. The major subroutines forming the OVLY12 are shown in Fig. 3. The subroutines marked with double frames were revised in the present work. The important subroutine for the macroscopic transport calculation is "GETFLT" in which the macroscopic cross sections for nucleons are given by the systematics of Pearlstein[8]. The flight path lengths are determined based on the macroscopic cross sections. The energy loss by the slowing down process is taken into account for charged particles. The subroutine "CASCAD" determines the type of nucleon-nucleon collisions by a random sampling from uniform probability distribution. If the elastic event is selected, the energy and direction of a scattered particle are calculated. If the non-elastic event is chosen, the nuclear reaction calculation begins in the subroutine "OVLY22" called from CASCAD.

(4) Intranuclear Cascade Calculation Package

The intranuclear cascade process is calculated with the Bertini model[13] in the subroutines subject to the routine "BERT". The version of MECC-3 [5] is installed in NMTC/JAERI97 in which slight modification was made. The package of ISOBAR[14] tuned to be executed on the UNIX system and personal computer by Fraenkel is also available for the intranuclear cascade calculation. The major subroutines relevant to the routines BERT and ISOBAR are shown in Fig. 4. The details of those models are described in the section 3.1.

(5) Preequilibrium Calculation Package

The preequilibrium process is calculated by the exciton model developed by Yoshizawa et al.[15] on the basis of the formulation proposed by Gudima et al.[16] and the algorithm proposed by Nakahara and Nishida[17]. The preequilibrium process is calculated in the subroutine "QDRES" before the evaporation process in the subroutine "ERUP". The emissions of six particles of proton, neutron, deuteron, triton, helium-3 and α-particle are taken into account. The simplified algorithm of the preequilibrium process is shown in Fig. 5. The details of the model are described in the section 3.2.

(6) Evaporation Calculation Package

The particle evaporation process is calculated in the subroutine "DRES". The original version of DRES was developed by Guthrie as "EVAP"[6]. NMTC/JAERI97 implements a slightly modified version from EVAP-4[18]. The emissions of six particles of proton, neutron, deuteron, triton, helium-3 and α-particle are taken into account. In this subroutine, the level density parameters are used to calculate the emission probability of the particles. A part of level density parameter values are tabulated in a file named "leveld.dat" and are read out from a source routine through the logical unit 30 at the beginning of calculation.

(7) High Energy Fission Calculation Package

The computation scheme of the high energy fission process proposed by Nakahara[7] is employed. The process is treated to be competitive with the particle evaporation process in the OVLY12.

(8) Nuclear Structure Data File

The nuclear structure data and the cross section data of elemental nucleon-nucleon and nucleon-pion reactions are given from the data file named "nmtclb25.dat" for the intranuclear cascade calculation with the Bertini model. For the intranuclear cascade calculation with the ISOBAR code, on the other hand, tabulated data and the values obtained with fitting formula are utilized. The data relevant to the nuclear structure are read out from the data file into the array "CRSC" in the order of the mass number, the nucleus radii, the nucleon density parameters and the Fermi energy parameters.

With these data, the nucleon density is given as

$$\rho_i^n = \rho_i(A-Z)\ ,\quad (i=1,3), \qquad \text{for neutron,}$$

$$\rho_i^p = \rho_i Z\ ,\quad (i=1,3), \qquad \text{for proton.}$$

Here, ρ_i indicates the nucleon density parameter of a region i in a target nucleus given in the units of $10^{30}/cm^3$, A the mass number and Z the atomic number. Furthermore, the Fermi energy is given as

$$E_i^n = U_i (A - Z)^{2/3} \text{ , } (i=1,3), \text{ for neutron,}$$

$$E_i^p = U_i Z^{2/3} \text{ , } (i=1,3), \qquad \text{for proton,}$$

where U_i represents the Fermi energy parameter of the region i in the target nucleus given in the units of MeV.

The nucleon-nucleon collision cross section data compiled by Bertini [13] are employed for the intranuclear cascade calculation. Those are also supplied from the data file. For the reactions of (π^-, p), (π^0, p), (π^+, p) and (π^0, n), the data file contains cross sections of elastic scattering and charge exchange, differential scattering cross section parameters, absorption cross section and non-elastic scattering cross section for one-pion production. For the (π^-, n), (π^+, n) reactions, the same data as for (π^+, p) and (π^-, p) are used because of the charge symmetry. The data file also contains elastic scattering cross sections, differential scattering cross section parameters, non-elastic scattering cross sections for single-pion and double-pion productions for (n, p) and (p, p). Since the effect of Coulomb force between the two protons is negligibly small in the energy region above 20 MeV, the cross sections of the (p, p) reaction are employed for the (n, n) one. These data are read through the logical unit 21 into the array "TAPCRS" in the source routine.

(9) Tally Package

The tally package has been newly implemented in NMTC/JAERI97 to obtain particle energy spectra, heat deposition and nuclide yield. The subroutines of the tally package are stored in the routine "TALLY". These subroutines are called in the subroutine "ANALY3" every time after an event is finished. The following 6 tallies are available : track length tally, surface cross current spectrum tally, surface cross flux tally, surface cross current tally, nuclide yield tally and heat deposition tally. The program tree for tally function is shown in Fig. 6.

3. Models and Data Implemented in the Code

3.1 Intranuclear Cascade Models

3.1.1 Bertini Model

The Bertini model treats the interaction between an incident particle and an intranuclear nucleon as a collision between free particles in the degenerated Fermi sea. The target nucleus is divided into three regions having the relative nucleon densities of 0.9, 0.2 and 0.01 to the nucleon density at the center of the nucleus. The Fermi energy of nucleons in each region is supplied by the parametrized data as described in the previous section. The constant value of 7 MeV is used as the binding energy of the intranuclear nucleons in each region.

In the simulation of a collision, the energies and momentums of particles after the collision are calculated in a frame of the relativistic dynamics. Here, the nucleon-nucleon (NN) cross sections in the free space are employed to calculate the mean free path of a travelling nucleon and collision probability. The directional cosines are determined by a random sampling from a function fitted to experimental data. The production of π meson via an excited state of a nucleon (Δ particle) is taken into account using the isobar model proposed by Lindenbaum and Steinheimer[19]. The Δ particle is assumed to decay into a nucleon and a π meson immediately in the Bertini model. The exclusion principle is applied by checking whether or not the kinetic energy of a struck particle reaches the cutoff energy which is set to the half height of Coulomb barrier above Fermi level. Reflection and refraction of a particle on the surface of the target nucleus and the boundary between the neighboring regions in the nucleus is not considered. The excitation energy U, the mass number A and the charge number Z are given as initial conditions to the following preequilibrium or evaporation calculations.

3.1.2 ISOBAR Code

In NMTC/JAERI97, the ISOBAR code[14] is employed as an alternative option for the intranuclear cascade calculation. The code is an extended version of VEGAS[14] to supplement the Δ particle capture, the Δ particle-nucleon exchange and so on to the treatment of the Δ particle-nucleon interactions[20]. In the ISOBAR code, the radius of a target nucleus, r, is defined as $r = 1.07 \times A^{1/3} + 2.5$ fm. The target is divided radially into 8 regions. The thickness of the outmost (1st) region is 1.0 fm. The next 5 regions have the thickness of 0.6 fm, and the 7th region has again that of 1.0 fm. Each region has the nucleon density, ρ_i, which corresponds to the fractions of 0.025, 0.1, 0.3, 0.5, 0.7, 0.9 and 0.975 to the nucleon density of the central (8th) region, respectively, where i denotes the region number. The Fermi energy for neutron and proton in the region i is given as

$$E^{n}_{Fi}=\frac{\hbar^2}{2m}(3\pi^2\rho_i)^{2/3}(A-Z)^{2/3}, \quad \text{for neutron,}$$

$$E^{p}_{Fi}=\frac{\hbar^2}{2m}(3\pi^2\rho_i)^{2/3}Z^{2/3} \quad , \quad \text{for proton,}$$

where A and Z indicate the mass and atomic number of the target nucleus. When a travelling particle crosses a boundary of two neighboring regions, the change of its direction of motion by the reflection and refraction at the boundary is calculated according to the Snell's law[21]. The parametrized in-medium NN cross sections similar to those of Cugnon[22] have been employed[23] instead of the free nucleon-nucleon ones to calculate the mean free path and collision probability of nucleon in a target nucleus. The parametrization is represented as follows [24] in the unit system that the light velocity, c, is regarded as unity :

$$\sigma=\frac{C_1}{1+100\sqrt{s'}}+C_2 \text{ (mb)}, \tag{1}$$

with $\sqrt{s'}=\max(0,\sqrt{s}-M_i-M_j-cutoff)$ (GeV), (2)

where M_i and M_j are the rest masses of a projectile and a struck nucleon in GeV, respectively. Here, $\sqrt{s}$ is the invariant energy of the two colliding nucleons, and is defined as follows:

$$\sqrt{s}=\left\{(E_1+E_2)^2-(\boldsymbol{p}_1+\boldsymbol{p}_2)^2\right\}^{1/2} \text{ (GeV)}, \tag{3}$$

with $E_i=(M_i^2+p_i^2)^{1/2}$ (GeV) , (4)

where $\boldsymbol{p}_i$ and E_i are the momentum in GeV/c and the total energy of the colliding nucleon i, respectively. In eq. (2), 0.02 GeV is employed as the cut-off. C_1 and C_2 are the elastic cross section parameters. The values of the parameters are set to be 35.0 and 20.0 mb for pp and nn collisions, while they are 28.0 and 27.0 mb for pn collision. This parametrization is applicable to the energy region from 40 MeV to 1 GeV in the laboratory frame. In the energy region below 40 MeV, the cross section extrapolated with the following parametrization[25] is employed :

$$\sigma=23.5+1000\times(0.7-p_{lab})^4 \text{ (mb)}, \tag{5}$$

where p_{lab} stands for the momentum in GeV/c of the nucleon in the laboratory frame. The resultant in-medium NN cross sections are shown with the free NN ones in Fig. 7(a) and 7(b).

Moreover, the ISOBAR code takes account of the threshold energies for (p, n) and (n, p) reactions to treat the quasi-elastic collision properly. The threshold energy is added to the cut-off energy which is the sum of the Fermi energy, the binding energy and the Coulomb barrier, and is used to check the escape possibility of a travelling nucleon after colliding in the target.

3.2 Preequilibrium Calculation Model

The next phase of the calculation is the preequilibrium process. The intranuclear cascade process is terminated when energies of all travelling particles reach below a cutoff energy, E_c. This cutoff energy is given by the use of a probability function expressed as

$$f(E_c)=\frac{2}{E_0}\left(1-\frac{E_c}{E_0}\right) , \tag{6}$$

where the value of E_0 is determined as 40 MeV. For the preequilibrium calculation, the closed form exciton model proposed by Gudima et al.[16] is adopted. The number of particles in the exciton state, p_0, at an initial stage of the preequilibrium process is the same as that of allowed collisions during the intranuclear cascade process. The number of holes, h_0, is p_0-1. The preequilibrium calculation is carried out in the framework of a Monte Carlo algorithm formulated by Nakahara and Nishida[17]. In the exciton model, the reaction rate is obtained by summing three kinds of transition rates concerning to the exciton states $\lambda_+(p,h,E)$, $\lambda_o(p,h,E)$ and $\lambda_-(p,h,E)$, and the particle emission rate. Here, the emission rate $\lambda_c^j(p,h,E,T)$ of a nucleon j is expressed as [16]

$$\lambda_c^j(p,h,E,T)=\frac{2S_j+1}{\pi^2\hbar^3}\mu_j R_j(p,h)\frac{\omega(p-1,h,E-B_j-T)}{\omega(p,h,E)}T\sigma_{inv}(T) , \tag{7}$$

where p = the number of particles,

h = the number of holes,

E = the excitation energy,

T = the kinetic energy of an emitted nucleon j,

$\sigma_{inv}(T)$ = the inverse cross section for the emission of nucleon j,

S_j = the spin of emitted nucleon j,

B_j = the binding energy of emitted nucleon j,

μ_j = the reduced mass of emitted nucleon j.

Here, $\omega(p, h, E)$ indicates the level density of the n-exciton state, which is obtained on the basis of the equidistant level scheme with the single-particle density. $R_j(p, h)$ is the factor which ensures the condition for the exciton chosen to be the nucleon j.

The transition rates are multiplied by a factor of F represented as F=max(0.2, 3.4-12/$A^{1/2}$), where A is the mass number of a target nucleus. The six kinds of particles of neutron, proton, deuteron, triton, helium-3 and α-particle are taken into account as the emitted particles. Here, the emission rate of cluster is obtained by replacing the term of $\omega(p\text{-}1, h, E\text{-}B_j\text{-}T)/\omega(p, h, E)$ in eq. (7) with

$$\gamma_j \cdot \frac{\omega(p-p_j, h, E-B_j-T)}{\omega(p, h, E)} \cdot \frac{\omega(p_j, 0, B_j+T)}{g_j} \quad . \tag{8}$$

Here,

$$\gamma_j = p_j^3 \left(\frac{p_j}{A}\right)^{p_j-1} , \tag{9}$$

and

$$g_j(T) = \frac{V(2S_j+1)(2\mu_j)^{\frac{3}{2}}}{4\pi^2\hbar^3}(T+B_j)^{\frac{1}{2}} , \tag{10}$$

where V stands for the nucleus volume.

The angular distribution of an emitted particle is assumed to be isotropic.

3.3 High Energy Fission Calculation Model

In NMTC/JAERI97, the high energy fission process is treated as a competitive process with the evaporation one. Before going to the evaporation stage, the fission reaction is selected if a random number exceeds the fission probability P_f represented with the fission width Γ_f and the neutron emission width Γ_n

$$P_f=\frac{1}{1+\Gamma_n/\Gamma_f} \tag{11}$$

According to a statistical model, the ratio of the neutron emission width to the fission one is given by the following equation :

$$\frac{\Gamma_n}{\Gamma_f}=\frac{4A^{2/3}a_f(U-Q_n)}{K_0 a_n[2\sqrt{a_f(U-E_f)}-1]}\cdot exp[\ 2\sqrt{a_n(U-E_n)}-2\sqrt{a_f(U-E_f)}] \tag{12}$$

with $$K_0=h^2/(8p^2 m r_0^2) \tag{13}$$

where Q_n the neutron binding energy, E_f the fission barrier height, a_n the level density parameter for neutron emission, a_f the one for fission, m the neutron mass and r_0 the nucleus radius. The ratio of the level density parameter a_f/a_n is determined by an expression fitted to the fission cross section data obtained by Il'inov et al.[26] for the incident proton energies of 150, 660 and 1,000 MeV. The data of Il'inov and those of Kupryanov et al.[27] are employed to determine the fission barriers for the nuclides with mass number $A\leq 224$ and for the ones $A\geq 225$, respectively. The mass distribution of fission fragments for sub-actinide nuclides is calculated using a Gaussian distribution with the half width derived by Neuzil and Fairhall[28]. For actinide nuclides, it is calculated with the folded Gaussian distribution with the parameters obtained by fitting to the data of Grass et al.[29] for the α-induced fission of ^{238}Pu. The charge of the fission fragment is determined by a Gaussian distribution with the parameters obtained by Pik-Pichak and Strutinskii[30] for the masses of given fragments. The detailed process to determine the residual fragments are reported in Ref. 7.

3.4 Evaporation Calculation Model

When an excited nucleus emits a particle by the evaporation process, the emission probability of a particle j, P_j, is represented as

$$P_j=(2S_j+1)\,m_j\,\varepsilon\,\sigma_{cj}(\varepsilon)\,\omega(E)\ , \tag{14}$$

with

$$E=U-Q_j-\varepsilon\,, \tag{15}$$

where S_j, indicates the spin of particle j, m_j the mass, Q_j the binding energy and σ_{cj} the inverse reaction cross section for the emission of particle j. As for the inverse reaction cross section, the value obtained by the empirical formula derived by Dostrovsky [31] is employed. In eqs. (14) and (15), ε and U indicate the kinetic energy of an emitted particle and the excitation energy of a compound nucleus, respectively. The $\omega(E)$ stands for the energy level density of a residual nucleus. It is given as

$$\omega(E)=\omega_0 exp\left[\, 2\sqrt{a\,(E-\delta)}\,\right] , \tag{16}$$

with

$$a=\frac{A}{B}\,(1+Y\frac{\Delta^2}{A^2}), \tag{17}$$

where δ is the pairing energy and a is the level density parameter, in which B is treated as a parameter in the code. Here, Δ is given as A-$2Z$ by the use of the mass number and the atomic number of a residual nucleus. A value of 1.5 is given to Y.

As far as the level density parameter is concerned, the following three options are available in NMTC/JAERI97: mass dependent value of $A/8$, the level density parameter derived by Baba[32] and that derived by Ignatyuk[33] with the parameters proposed by Mengoni et al.[34]. The Ignatyuk formula takes account of the excitation energy dependence in the level density. Those level density parameters are shown in Figs. 8(a) to 8(d).

In the evaporation process, the mass formula and the mass table are used to determine the binding energy of an emitted nucleon. The binding energy of a particle j is obtained on the basis of the mass excess as

$$Q_j = M(A - FLA(j), Z - FLZ(j)) + M(FLA(j), FLZ(j)) - M(A,Z) \;, \tag{18}$$

where $M(A, Z)$ indicates the mass excess of the nucleus having the mass number A and the atomic number Z. $FLA(j)$ and $FLZ(j)$ stand for the mass number and atomic number of an emitted particle j. The value of mass excess is obtained by the mass table compiled by Audi and Wapstra[35]. The mass formula derived by Tachibana et al.[36] is also employed to calculate the mass excess value of the nucleus which is not included in the mass table.

3.5 Nucleon-Nucleus Collision Cross Sections for Particle Transport

In the nucleon transport calculation, the type of collision, elastic or non-elastic, is determined by a random sampling according to the fraction of collision cross sections to the total one. The elastic and the non-elastic collision cross sections of nuclear reactions are given by the systematics proposed by Pearlstein[8)] in the energy region below 1 GeV except for hydrogen. The total and elastic cross sections obtained by the systematics are shown in Fig. 9(a) and 9(b), respectively, for ^{12}C, ^{27}Al, ^{56}Fe, ^{90}Zr, ^{184}W and ^{208}Pb. As far as the hydrogen nucleus is concerned, the cross sections evaluated by Chiba[37)] are implemented as data table in the code.

If the non-elastic scattering is selected, the pseudo event is excluded and the trial for the nuclear reaction calculation is repeated until a real event occurs because the non-elastic collision is selected on the basis of the cross section data by the random sampling. Here, the pseudo event corresponds to the phenomenon that an incident particle passes through a target nucleus without colliding with an intranuclear nucleon.

If the elastic scattering is selected, angular distribution of scattered nucleon is determined according to the same way as the treatment in the HETC/KFA2 code[38)]. According to the ref. 38, the angular distribution is approximately represented by fitting with the first order Bessel function J_1.

$$\frac{d\sigma}{d\Omega}=\frac{R^4}{(\hbar c/pc)^2}\left\{\frac{J_1[\,2R\sin(\theta/2)/(\hbar c/pc)\,]}{2R\sin(\theta/2)/(\hbar c/pc)}\right\}^2 \tag{19}$$

with

$$R=r_0 A^{1/3}+\lambda. \tag{20}$$

where θ stands for the scattering angle in the center of mass system and λ is given by the following relation :

$$\lambda=\hbar c/pc\ , \tag{21}$$

with

$$pc=\sqrt{E\,(E+2m)}\ . \tag{22}$$

Here, $\hbar c$ = 1.9732 x 10^{-11} MeV·cm. E and m indicate the kinetic energy and the mass of an incident nucleon. From eq. (19), the angular distribution is represented as the form of $f(x) \propto$

$[J_1(x)/x]^2$. The function $J_1(x)/x$ can be expanded to the following polynomial:

$$J_1(x)/x = 1/2 - x^2/16 + x^4/384 - x^6/18432, \tag{23}$$

where the value of x lies in the range from 0 to the first zero of J_1 , and the maximum value of x is $0.610/2\pi$. By the use of the values in eqs. (20) to (23), the scattering angle in the center of mass system is obtained as

$$\cos\theta = 1 - x^2 / (2\{7.095 \times 10^{-3} \cdot A^{-1/3} \cdot \sqrt{E(E+1878)} + 1\}^2). \tag{24}$$

4. Description of Geometry Configuration

The geometry configuration of a problem is described with the extended version of Combinatorial Geometry (CG) package, MARS (Multiple Array System)[9,10] in NMTC /JAERI97. The concepts of "body", "zone" and "region" are introduced in MARS for expressing the geometry configuration. These three concepts are defined as follows:

1) Body is the unit configuration such as rectangular parallelepiped, sphere, right circular cylinder and so on for describing the geometry configuration.
2) Zone is the minimum unit of the geometry configuration and is defined by the combination of bodies using the set operator such as unions, differences and intersections. Zone is composed of a single material and belongs to a single region.
3) Region is a unit of a spatial region where tallies are set and is defined by the unions of some zones.

The following 13 kinds of basic geometry shapes (bodies) are prepared in the present MARS:

(a) Right parallelepiped (RPP)
(b) Sphere (SPH)
(c) Right Circular Cylinder (RCC)
(d) Right Elliptical Cylinder (REC)
(e) Truncated Right Angle Cone (TRC)
(f) Ellipsoid (ELL)
(i) Right Angle Wedge (WED)
(j) Box which specifies the vertex and one of the corner (BOX)
(k) Arbitrary Polyhedron (ARB)
(l) Alternative Body Description (BPP or WPP)
(m) General Ellipsoid (GEL)
(n) Truncated Right Elliptical Cone (QUA)
(o) Torus (TOR)

Illustrations of these bodies are shown in Figs. A-1 to A-13 of Appendix A. The coordinate systems required to describe the bodies are summarized in Table A-1 of Appendix A. The type of body is recognized in the code by the three-character identification index indicated in the above parentheses.

Zone is defined by the combination of bodies using the set operator. The blank character " " and the "OR" notation are the operators meaning the intersection (AND) and the union (OR) of the two bodies, respectively. The "+" and "-" characters are also attached ahead of the body identification number. The "+" character means that the zone is inside the body. In this case, it is possible to omit the "+" character. The "-" character, on the other hand, means that the zone is outside the body. There is no limitation to the number of body used to define a zone. Some examples of zone description are shown as follows.

"+2 +3" : The zone is the intersection of "the inside of the body 2" and "the inside of the body 3".

"+2 -3" : The zone is the intersection of "the inside of the body 2" and "the outside of the body 3".

"+2 OR +3" : The zone is the union of "the inside of the body 2" and "the inside of the body 3".

"+1 -2 -3" : The zone is the intersection of "the inside of the body 1" and "the outside of the body 2" and "the outside of the body 3".

These examples are also illustrated in Fig. A-14 of Appendix A. In the input card, the zone is given with a three-character title. An "END" card is also required to terminate the reading of the zone description cards. An example of zone description input card is as follows.

```
ZN1  +1
ZN2  +2  -1
VID  +3  -2
END
```

In NMTC/JAERI97, any geometry can be modelled using only the above ordinary CG manner. For special cases to define geometry configurations composed of assemblies of some elements such as reactor core composed of fuel assemblies, human body phantom and so on, the features of MARS, "array" and "universe", are useful to describe such geometries. The relation between arrays and universes is shown in Fig. A-15 of Appendix A. The array is a regular rectangular lattice composed of rectangular cells of arbitrary content. The size of the array is defined by giving the number of cells along X, Y and Z axes, respectively. The arrays are sequentially labelled from 1 as they are entered in the input card. In order to terminate the entries for arrays, zero should be supplied in the card. After this termination input, a single integer parameter is required to define the input specification method, in other words, the data format. An example of the input card for an array is shown as follows.

Example : 10 10 1 7 4 2 6 6 1 0 0

This example describes three arrays. Array 1 will be a 10 by 10 by 1 array. Array 2 will be a

7 by 4 by 2 array. And, the array 3 will be a 6 by 6 by 1. The next zero is for terminating the array size input. The last zero indicates that the free-form input specification method is selected to define the array contents. The options of the input specification methods are explained in the remarks of input card number 17 in Section 7.2. The user must give the contents of each cell of each array according to the data format selected by the input specification option. The details are described as the explanation of input card number from 18A to18C in Section 7.2.

The universe is defined as the separate unique geometry modelled by CG and so can describe nested structures and array system. A universe has a separate independent dimension in space defined by a collection of input zones bounded by a special boundary media. Every input zone resides in the universe and must include the universe number containing the zone. The contents of the universe are arbitrary, and the universe may contain an array in one or more of its input zones. The most global universe is called as absolute universe and is designated as universe 0. All universes with exception of the absolute universe must be surrounded with the outer void. The coordinates in the universe can be defined independent of those in other universes. The universe number is given with a positive integer in the input card from 18A to 18C.

Figure A-16 of Appendix A shows a sample geometry configuration which can be described using the function of array and universe. As seen in the Figs. A-16(c) and A-16(d), the array can be defined in different ways using a single universe or different universes. The geometry description data for each case are shown in Figs. A-17 and A-18, respectively. It is possible to describe the geometry with very simple input data by setting single universe as shown in Figs. A-16(c) and A-17. However, the information about each cell (element) in the array can not be obtained by the NMTC/JAERI97 calculation because the region number is not assigned to individual cell but to region of the universe. The present NMTC/JAERI97 recognizes the region number of an universe as that for tally function. If the user wants to know the information about each cell of the array, the cell must be composed of a universe different from the others as shown in Figs. A-16(d) and A-18.

5. Importance Sampling

NMTC/JAERI97 implements the function that can calculate effectively the spectrum of particles with an importance sampling technique by setting a weight to a particle in each region. The statistical errors are also calculated taking account of the weight of a particle. The present importance sampling is carried out in the following procedure when a particle having a weight of "w_t" moves from the current region with an importance of "w_1" to the next region with that of "w_2".

(1) The ratio of the importance of neighboring regions is calculated as $r = w_2/w_1$.

(2) If $r > 1.0$ then, a sampling with a uniform random number x is performed. If $x \geq r - n$ where n is the integer with the condition of $n \leq r \leq n+1$, a parent particle is divided into n particles with a weight of w_t/r, and then particles with the number of $n-1$ are banked for the next transport calculation. If $x < r - n$, the parent particle is divided into $n+1$ particles with the weight of w_t/r, and the particles with the number of n are banked. Here, the information of the particles such as energy, position and directional cosines are succeeded with the one of parent particles except for the weight information. This procedure is generally called as splitting technique.

(3) If $r < 1.0$ then, a sampling is performed on the basis of a uniform random number. If the selected random number is less than r, the particle is survived and simulated with a weight of w_t/r. If the random number is greater than r, the transport calculation of the particle is terminated. This procedure is generally called as Russian roulette technique.

(4) If $r = 1.0$ ($w_2 = w_1$) or the importance of the next region is zero, the particle goes to the next region keeping the current weight w_t.

If the importance sampling is executed in the calculation, the summary table of the importance sampling is printed out.

6. Tally Function

In NMTC/JAERI97, the statistics calculation is executed in the same run of main program. The following six tallies are prepared for statistics calculation: (a) track length tally, (b) surface crossing current spectrum tally, (c) surface crossing flux tally , (d) surface crossing current tally, (e) nuclide yield tally and (f) heat deposition tally. The output of these information can be controlled by setting a flag in the input card 24. In the present version of NMTC /JAERI97, the surface crossing tallies listed in (b) to (d) are effective only for the surface at the z-direction given in the geometry input card.

(a) Track Length Tally

The track length tally calculates the flux in a certain region by the following representation:

$$\phi_j(E)=\frac{\sum_i w_i \cdot l_i}{V_j \cdot dE \cdot N}, \qquad (25)$$

where,

w_i : i- th particle weight,

l_i : track length of i - th particle in the specified region j [cm],

V_j : volume of the region j [cm^3],

dE: energy bin width [MeV or lethargy],

N: number of source particles.

(b) Surface Crossing Current Spectrum Tally

The surface crossing current spectrum tally estimates neutron current in a certain region as:

$$J_k(E)=\frac{\sum_i w_i(\mu, E)}{S_k \cdot dE \cdot N}, \qquad (26)$$

where,

$w_i(\mu,E)$: weight of i -th particle crossing the specified surface k with directional cosine μ and energy E,

S_k : area of the surface k [cm2],

dE: energy bin width [MeV or lethargy],

N: number of source particles.

(c) Surface Crossing Flux Tally

The neutron flux in a certain region is calculated by the surface crossing flux spectrum tally as:

$$\phi_k(E) = \frac{\sum_i w_i(\mu, E)}{S_k \cdot dE \cdot N} \cdot \frac{1}{|\mu|}, \tag{27}$$

where,

$w_i(\mu,E)$: weight of i -th particle crossing the specified surface k with directional cosine μ and energy E,

S_k : area of the surface k [cm2],

dE: energy bin width [MeV or lethargy],

N: number of source particles.

(d) Surface Crossing Current Tally

Since the current is independent of both the directional cosine and energy of particle, it is calculated by the surface crossing flux spectrum tally as:

$$J_k = \frac{\sum_i w_i}{S_k N}, \tag{28}$$

where,

w_i: weight of i -th particle crossing the specified surface k

S_k : area of the surface k [cm2],

N: number of source particles.

(e) Nuclide Yield Tally

The nuclide yield tally calculates nuclide production yield region by region. The number of produced nuclides are counted for 48 isotopes at maximum per one nucleus and then normalized to one incident particle.

(f) Heat Deposition Tally

The heat deposition tally calculates the heat produced by various process in a medium. The source of heat deposition is classified into the following 7 items in the present version:

i) Energy loss of charged particles of proton, pions and muons through the slowing down process.

ii) Energy deposition by particles proton, pions and muons reached the cut-off energy for particle transport.

iii) Energy deposition by fission fragments.

iv) Energy deposition by charged particles of deuteron, triton, He-3 and α-particle emitted from the evaporation process.

v) Energy deposition by the struck nucleus after the elastic scattering.

vi) Energy deposition by recoiled nucleus emitting particles in the evaporation process.

vii) Deposition of excitation energy of residual nucleus after the evaporation process.

In the process vii), some γ-rays with certain energy can be emitted. These γ-rays deposit their own energy through the transport process in a medium. The present NMTC/JAERI97, however, cannot estimate the γ-ray production yet. Since the assumption that all of the excitation energy of residual nucleus are lost at the position where a nuclear reaction occurred does not hold, the item vii) is excluded from the total amount of energy deposition in the present version. However, the component of the item vii) is listed out to the output file through the logical unit 62. This may lead to an underestimation for the heat deposition.

The kinetic energy carried by the particles which go out of the medium and the energy of neutrons which reach the cut-off energy for the following low-energy transport calculation are also written out to a file through the logical unit 6 for the energy balance check.

In the statistical treatment process using tally, the statistical error, σ, is also estimated as

$$\sigma=\frac{\sum_{n=1}^{N} wt_n^2}{(\sum_{n=1}^{N} wt_n)^2}-\frac{1}{N}, \qquad (29)$$

where N indicates the total number of incident particles, wt stands for the weight of particle counted in the tally.

7. User Guide to NMTC/JAERI97

7.1 Installation

The program of NMTC/JAERI97 is described with the FORTRAN77 language. NMTC/JAERI97 runs on the UNIX machines of FUJITSU S-7/300 (OS: Solaris 2.5) installing SPARCompiler FORTRAN77 ver. 4.0 and the Hewlett Packard HPUX-9 with available FORTRAN Compiler.

Figure 10 shows the default directory structure of NMTC/JAERI97. Data libraries and specified variables are separated from the source routines. The former contains nuclear data and level density parameters for the nuclear reaction calculation. The latter is divided into two groups. One is those referred from many source routines using common blocks. The other defines the maximum values of array elements concerning to the tallies, the number of materials treated in a problem. The variables belonging to the first group are stored in three files with the names of "COM", "COMON" and "ISOBA". Those of the second group are contained in the file named "PARM". Since the values of array elements are the index for the computer memory size required to the calculation, those can be flexibly adjusted according to the user's computer memory. All of those variables are referred from individual subroutine with the INCLUDE statement.

7.2 Input Data Preparation

NMTC/JAERI-97 requires 34 input cards at maximum. Figure B-4 of Appendix B shows an example of input card for the sample problem illustrated in Fig. B-1. The type of variables used in the input card is subject to the implicit form of FORTRAN77 language unless the type is specified explicitly. In short, the variable is an integer when its head character is written in the alphabet from "I" to "N", otherwise that is the real. The character in the parentheses after the card number represents the format of the input data. Here, the character "*" means that the card data are given by a free format, and the character "free" means that the data are given by the free format defined in the CG. Moreover, the remarks given in the blocks right after the characters indicating the data format represent the conditions for giving the input card. The input card should be omitted unless the conditions are satisfied. Finally, the notation with parentheses such as "WTREGN(1: irtu)" means that the variable is the array having "*irtu*" elements. The following summarizes the input card, variables and their function.

CARD 1 (A80)

(1) IA1: Title (up to 80 characters)

CARD 2 (A80)

(1) IA2: Title (up to 80 Characters)

CARD 3 (*)

(1) RANDKK: Initial random number.

Note: It is recommended that the value of 0.0 or blank character should be supplied in the first run. For the run successive to the previous one, the user should give the next initial random number, which is shown in the end of the output file for a summary of calculation, by the format of F16.0 (see Section 7.4(2)).

(2) IRSKP: The number of random number skipped from the initial one.

Note: This value is given for debugging. The value should be zero in the normal calculation.)

CARD 4 (*)

(1) EMAX: The maximum energy of incident particle in MeV. The upper limits for nucleon and pions are 3500 and 2500 MeV for Bertini model, respectively. For ISOBAR calculation, the limit is 1000 MeV.

(2) EMIN(1) : The low energy cutoff for protons in MeV. The minimum value is 1 MeV.

(3) EMIN(2) : The low energy cutoff for neutrons in MeV. The minimum value is 1 MeV.

Note: It is recommended that the value of 20.0 MeV should be used because it is much more reliable to use conventional neutron transport calculation code such as MCNP4A using a cross section library made from the evaluated nuclear data files rather than to use NMTC/JAERI97.

(4) MXMAT : The number of different media excluding voids. ($1 \le MXMAT \le 16$, this upper limit can be adjustable by changing the parameter file "param". See Section 7.1.)

(5) MAXCAS : The number of source particles per one batch.

(6) MAXBCH : The number of batches in a run. (1≤MAXBCH≤200, this upper limit can be adjustable by changing the parameter file "param". See Section 7.1.)

(7) N1COL : (Not used: zero should be given to this variable.)

CARD 5 (*)

(1) NQUIT : The number of calculation repetitions.
Note : Usually the value should be unity.

(2) NEUTP: 23 (Logical unit number for temporary working file, but not used in the present version.)

(3) NBERTP : 21 (Logical unit number for nuclear structure data input.)

(4) NPOWR2 : 11 (Logical unit number for temporary working file, but not used in the present version.)

(5) NPIDK : The option for the treatment of π^- particle.

≤ 0 : π^- reaction is taken into account.

> 0 : π^- decays immediately.

(6) NHSTP : 22 (Logical unit number for output of history data, but not used in the present version.)

CARD 6 (*)

(1) ANDIT : The angular distribution of an isobar created by a nucleon-nucleon collision in a nucleus.
= 0 : 50% isotropic distribution, 50% forward.
= 1 : Isotropic distribution.
= 2 : 100% forward.

(2) CTOFE : The cut-off energy. (Not used. Zero should be given.)

(3) NBOGUS: The option for the evaporation calculation.
< 0 : The evaporation calculation is not executed.
> 0 : The recoil energy of a residual nucleus is subtracted from the excitation energy of the residual nucleus.
= 0 : The recoil energy of the residual nucleus is not taken into account.

(4) NSPRED: The repulsive enlargement of incident proton beam due to the Coulomb force.
≤ 0 : No effect.
> 0 : This effect is taken into account.

(5) NWSPRD: The option for recording tracks of incident protons.

≤ 0 : Not recorded.

> 0 : Tracks of incident protons are recorded.

(6) NSEUDO: The option for recording the information of pseudo event.

≤ 0 : Not recorded.

> 0 : The information of pseudo event is recorded.

CARD 7 (*)

(1) IELAS : The option for the treatment of nucleon-nucleus elastic evaporation calculation.

= 0 : Geometrical cross sections are employed.

= 1 : Nucleon-nucleus cross sections given by Pearlstein's systematics are employed only for neutron below 1 GeV.

= 2 : Nucleon-nucleus cross sections given by Pearlstein's systematics are employed for neutron and proton below 1 GeV.

Note: The option 0 is not recommended because of their crudeness below 200 MeV.

(2) ICASC : The option for the intranuclear cascade calculation.

= 1 : Bertini model (default).

= 2 : ISOBAR code.

(3) IQSTEP: The option for preequilibrium calculation.

= 2 : Intranuclear cascade-evaporation calculation is executed.

= 3 : Intranuclear cascade-preequilibrium-evaporation calculation is executed.

Note: The option 3 is not recommended when the ISOBAR code is selected in above (2).

(4) LVLOPT: The option for level density parameter.

= 1 : 8/A is given.

= 2 : The level density parameters derived by Baba are employed.

= 3 : The level density parameters given by the Ignatyuk are employed.

The following card set of 8A and 8B must be repeated MAXMAT times.

CARD 8A (*)

(1) DENH(M): The hydrogen (^{1}H) number density in the M-th medium in the units of 10^{24} atoms/cm^{3}.

(2) NEL(M): The number of nuclides other than ^{1}H in the M-th medium. If the medium is composed of hydrogen only, it is necessary to give a dummy nuclides with an extremely low number density in the CARD 8B. (1≤NEL≤17, this upper limit can be adjustable by changing the parameter file "param". See Section 7.1.)

CARD 8B (*) (repeat NEL times.)

(1) ZZ(L,M) : The atomic number of L-th nuclide in the M-th medium.

(2) A(L,M) : The mass number of L-th nuclide in the M-th medium.

(3) DEN(L,M) : The number density of L-th nuclide in the M-th medium in the units of 10^{24} atoms/cm^3.

CARD 9 (A60)

(1) TITLE : The comment card for the geometry of the problem.

CARD 10 (free)

(1) IVOPT: Not used. Zero should be given.

(2) IDBG : Debug print option

= 0 : There is no effect.

> 0 : The debug print is executed.

(3) IBOD : Body number assignment option

= 0 : There is no effect.

> 0 : The body number is given.

(4) NAX: Number of zones to be added to the data storage for next zone of entry memory table. Enter any large number if extra storage is required. Default value is 5.

The following CARD 11 must be given for each body and for the END line.

CARD 11 (Free)

(1) ITYPE: A three-character body type identification index or the notation "END" to terminate reading the body data. As described in Chapter 4, the body type is represented with a three-character identification index such as BOX, RPP, ARB, RCC and so on. The identification index is listed in Table A-1 of

Appendix A. The illustrations of bodies treated in the code are shown in the Figs. A-1 to A-13 of Appendix A.

(2) IALP : The body number assigned by the user if IBOD is greater than zero; otherwise it is not entered.

(3) Body (1: N) : The real data required for the given body in the units of cm. The real data for each body are summarized in Table A-1.

The following CARD 12 must be given for each zone and for the END line.

CARD 12 (Free)

(1) IREG: The identification name for a region defined by the user. The name is given within three characters whose first one is given by an alphabet. The three-character "END" must be given to terminate reading the zone data.

(2) IIBIAS(L:N): The identification index for the "OR" operator if required for the JTY(I) body.

(3) JTY(L: N): The body number with the "+" or "-" character is required for the zone description as instructed in Chapter 4. If the zone is inside of the body, the character "+" should be attached ahead of the number. If not so, the character "-" is required.

Example :

```
ZN1  OR +1 -2  OR +2
ZN2  -2  +3
VID  -3  +4
END
```

CARD 13 (Free)

(1) IWL(L: N) : The region number required for the input zone defined in the CARD 12.

CARD 14 (Free)

(1) IWU(L: N) : The universe number included in each region defined in the CARD 12. The entry must be either zero or a positive integer. A negative entry is not valid. If the ordinary combinatorial geometry is used, in which array structure is not adopted, zero must be given to each region. In this case, the universe number can be supplied as NREG*0, where "NREG" indicates the number of regions defined in the CARD 12. It is also possible to enter zero region by region.

Each universe, with the exception of the absolute universe, must contain one and only one zone with an outer boundary of universe represented as "-1000" in the following input card. The absolute universe cannot contain any outer void zone.

CARD 15 (Free)

(1) MEDIA (1: N) :

The media number assigned to the region defined in the CARD 12. Here, a negative entry refers a valid array number and the absolute value of the entry corresponds to the array number. The following numbers have special meanings as

= 0 : outer void,

= 1000 : inner void,

= -1000 : outer boundary of universe.

CARD 16 (Free)

(1) NXMAX: The length of an array along X-direction. If array is not used, zero must be given.

(2) NYMAX: The length of an array along Y-direction. If array is not used, zero must be given.

(3) NZMAX: The length of an array along Z-direction. If array is not used, zero must be given.

Note: Even if array is not used, the CARD 16 is required to identify that array is not used in the geometry description. An array is a regular rectangular lattice composed of rectangular cells of arbitrary content. The size of array should be entered as NXMAX, MYMAX by NZMAX. Arrays are sequentially labelled from 1 as they are entered. The array size entered should include any vacant cells in the array, if any are present. After the size of the last array has been entered, a zero should be entered to terminate the entries. Zero is an illegal entry for array size.

The following cards from 17 to 19 are omitted unless the array is used.

CARD 17 (free)

(1) IOP : Option for Array specification.

= 0 : Free-Form FIDO style

= 1 : Do loop style, (the same as that adopted in KENO code).

= 2 : Standard FIDO style, (the same as that adopted in ANISN code).

CARD 18A (free) [IOP = 0]

(1) NCA(1: NXMAX, 1: NYMAX, 1: NZMAX, 1: NAR) :

The contents of each cell of each array. The number of cells along X-direction, NXMAX, should be given at first. Then, that along Y-direction, NYMAX and that along Z-direction, NZMAX, are given, respectively. Those data must be required to repeat NAR times. Here, if a positive value is given, the cell is universe. The negative one means that the cell is array. When zero is supplied, the cell is empty.

CARD 18B (free) [IOP = 1]

(1) LTYPE : The number of a cell. The positive, negative and zero values indicate that the cell is universe, array and empty cell, respectively.

(2) IX1 : The starting point of the cell LTYPE in the X-direction. This value must be at least 1 and less than or equal to NXMAX.

(3) IX2 : The ending point of the cell LTYPE in the X-direction. This value must be at least 1 and less than or equal to NXMAX.

(4) INCX : The number of cells by which increments are made in the positive X-direction. INCX must be greater than zero and less than or equal to NXMAX.

(5) IY1 : The starting point of the cell LTYPE in the Y-direction. This value must be at least 1 and less than or equal to NYMAX.

(6) IY2 : The ending point of the cell LTYPE in the Y-direction. This value must be at least 1 and less than or equal to NYMAX.

(7) INCY : The number of cells by which increments are made in the positive Y-direction. INCY must be greater than zero and less than or equal to NYMAX.

(8) IZ1 : The starting point of the cell LTYPE in the Z-direction. This value must be at least 1 and less than or equal to NZMAX.

(9) IZ2 : The ending point of the cell LTYPE in the Z-direction. This value must be at least 1 and less than or equal to NZMAX.

(10) INCZ : The number of cells by which increments are made in the positive Z-direction. INCZ must be greater than zero and less than or equal to NZMAX.

(11) INTP :

= 0 : read another set of data.

≠ 0 : do not read any more mixed-cell orientation data.

The data sets IX1, IX2, INCX and so on from (2) to (10) correspond to the variables which specify the starting value, ending one and increments of do-loop statement in the FORTRAN language. An important feature of this type of data description is that, if any portion of an array is defined in a conflicting manner, the last card to define that portion will be the one that determines the array's cell type configuration. To utilize this feature, one can superimpose the other cell types in their proper places to accurately describe the array. The last set of mixed-cell orientation data must have a non-zero entry in the last field.

CARD 18C (free) [IOP=2]

The description for each lattice array is entered as a single array block with FIDO. The FIDO integer array number is the array number being described plus 100. Since the array being entered is integer, it is a "$" or "$$" array. The data is entered and each array description is terminated with "T". Thus, Array 1 would be entered as the "101$$". All standard FIDO repeat options are available for entering the data. The format for the data entry is the same as the description for free-form input. All x entries for the first y row and first z level are entered, then all x entries for the second row and first z level are entered. This process continues until the entire first z level has been described. Then, the second level is described until the entire array has been described. Then, the geometry array description or a given array is terminated with a "T."

CARD 19 (free)

(1) ITU(1: N) : Type of universe. The entries should be either zero or 1.

= 0 : Universe is "combinatorial".

= 1 : Universe is "simple".

A "simple" universe is a universe composed of concentric zones, where every zone completely surrounds the zone inside of it. Furthermore, input zones in a simple universe may be only one code zone and may be described by only one or two bodies. Figure A-19 of Appendix A shows the sketches of a simple and a combinatorial universe.

CARD 20A (A10)

(1) HIMP : Option for the importance sampling function to individual region

= “importance” : importance sampling function is adopted.

= “no-importa” : importance sampling function is not adopted.

If characters other than above defined ones are given, the input to CARD 20A and CARD 20B is omitted, and the function does not work.

CARD 20B (*)

This card is required in the case that HIMP=“importance”.

(1) WTREGN(1: IRTRU) :

Importance of each region. Both of integer and real form are available. IRTRU is the number of regions defined in CG in CARD 12. This determines the set of particle weights for splitting and Russian roulette to be used in each zone during tracking for CG.

CARD 21 (A10, *)

(1) HL(1: 10) = “source” (fixed word).

(2) J : Option for the source particle distribution.

= 1 : Cylinder or circle including pencil beam

= 2 : Rectangular

= 3 : Gaussian distribution

= 4 : Cylinder in which source particles have an energy distribution.

= 5 : Rectangular in which source particles have an energy distribution.

CARD 22A (*) [J = 1 or 4]

(1) R0 : The radius of cylinder in cm. Zero is given for pencil beam.

(2) Z0 : The lower limit of axial position in cm.

(3) Z1 : The upper limit of axial position in cm.

(4) E0 : The maximum incident particle energy in MeV.

(5) TIP0 : Option for the type of incident particle.

= 0 : proton

= 1 : neutron

= 2 : π^+

= 3 : π^0

= 4 : π^-

(6) TL : Time limit (not used)

(7) DIREC : Option for the directional cosine about Z-direction.

= 1.0 : + Z-direction

= -1.0: - Z-direction

CARD 22B (*) [J = 2 or 5]

(1) X0 : The lower limit on X-axis of a rectangular in cm.

(2) X1 : The upper limit on X-axis of a rectangular in cm.

(3) Y0 : The lower limit on Y-axis of a rectangular in cm.

(4) Y1 : The upper limit on Y-axis of a rectangular in cm.

(5) Z0 : The lower limit on Z-axis of a rectangular in cm.

(6) Z1 : The upper limit on Z-axis of a rectangular in cm.

(7) E0 : The maximum incident particle energy in MeV.

(8) TIP0 : Option for the type of incident particle.

= 0 : proton

= 1 : neutron

= 2 : π^+

= 3 : π^0

= 4 : π^-

(9) TL : Time limit (not used)

(10) Direc : Option for the directional cosine about Z-direction.

= 1.0 : + Z-direction

= -1.0: - Z-direction

CARD 22C (*) [J = 3]

(1) X0 : The center value on X-axis of a gaussian distribution in cm.

(2) X1 : The full width half maximum value on X-axis of a gaussian distribution in cm.

(3) Y0 : The center value on Y-axis of a gaussian distribution in cm.

(4) Y1 : The full width half maximum value on Y-axis of a gaussian distribution in cm.

(5) Z0 : The center value on z-axis of a gaussian distribution in cm.

(6) Z1 : The full width half maximum value on Z-axis of a gaussian distribution in cm.

(7) E0 : The maximum incident particle energy in MeV.

(8) TIP0 : Option for the type of incident particle.

= 0 : proton

= 1 : neutron

= 2 : π^+

= 3 : π^0

= 4 : π^-

(9) TL : time limit (not used)

(10) Direc : Option for the directional cosine about Z-direction.

= 1.0 : + Z-direction

= -1.0: - Z-direction

If source particles have energy distribution, the following cards 23A and 23B are required.

CARD 23A (*)

(1) NGRP : The number of energy group (< 100).

CARD 23B (*)

(EGMIN(I), FEGRP(I), I = 1, NGRP), EGMAX

(1) EGMIN : The lower limit energy of each energy group in MeV.

(2) EFGRP : The relative source intensity of each energy group.

(3) EGMAX : The maximum energy in MeV.

CARD 24 (A10, *)

(1) HL(1: 10) : The identification word. This word is selected from the following three options and filled in the column between 1 and 10.

= "tally*" : Integer option.

= "all tally": All tally assignment option. The character "all-tall" is also acceptable.

= "tally" : Character option.

In case of "tally*",

(2) ITALXX(1) : Option for the track length tally.

= 0 : no effect.

= 1 : Track length tally is used.

(3) ITALXX(2) : Option for the surface crossing spectrum tally.

= 0 : no effect.

= 1 : Surface crossing spectrum is calculated.

(4) ITALXX(3) : Option for the surface crossing flux tally.

= 0 : no effect.

= 1 : Surface crossing flux is calculated.

(5) ITALXX(4) : Option for the surface crossing current tally

= 0 : no effect.

= 1 : Surface crossing current is calculated.

(6) ITALXX(5) : Option for the nuclide yield tally

= 0 : no effect.

= 1 : Nuclide yield is calculated

(7) ITALXX(6) : Option for the heat deposition tally.

= 0 : no effect

= 1 : Heat deposition is calculated in each region.

In case of "tally",

(2) HLTAL : The name of tally to be selected. If some tallies are used in a single calculation, CARD 24 is repeated the same number as required.

= "track" : Track length tally

= "surface" : All of three surface crossing tallies

= "surface-spect" : Surface crossing spectrum tally

= "surface-flux" : Surface crossing flux tally

= "surface-current" : Surface crossing current tally

= "yield" : Nuclide yield tally

= "heat" : Heat deposition tally

CARD 25A (A10, *)

(1) HL(1: 10) = "energy" (fixed word).

The identification word for tally energy group definition. This word should be entered in the column between 1 and 10.

(2) NENG : The number of energy group in a tally.

CARD 25B (A10, *)

(1) HL(1: 10)= "energy" (fixed word).

(2) EB(1: NENG+1) :

The boundary value of each energy group in MeV. This value should be entered from the lowest energy boundary to the highest one in the increasing order.

If none of track length tally, nuclide yield tally and heat deposition tally are used, the cards 26 and 29 are omitted.

CARD 26 (A10, *)

(1) HL(1: 10)="volume" (fixed word).

The identification word for volume definition. This word should be entered in the column between 1 and 10.

(2) VOLREG(1: IRTRU) :

The volume of each region in cm^3. The values have to be given with the same order as region numbers. The default value of 1.0 cm^3 is supplied if the number of entries is less than that of regions.

CARD 27A (A10,*)

(1) HL(1: 10)="r-surf" :

The identification word for radial position data for surface crossing tally. This word should be entered in the column between 1 and 10.

(2) NRSURF : The number of radial positions for surface crossing tally

CARD 27B (A10,*)

(1) HL(1: 10)="r-surf", (fixed word).

(2) BR(1: NRSURF) :

The radial position for surface crossing tally of the R-Z two-dimensional cylindrical model. The unit is in cm. The values have to be given with the increasing order.

CARD 28A (A10,*)

(1) HL(1: 10)="z-surf" :

The identification word for axial position data for surface crossing tally. This word should be entered in the column between 1 and 10.

(2) NZSURF : The number of positions of surface crossing tally in the axial direction.

CARD 28B (A10,*)

(1) HL(1: 10)="z-surf", (fixed word).

(2) BZ(1: NZSURF) :

The axial position in cm for surface crossing tally of the R-Z two-dimensional cylindrical model. The unit is in cm.

CARD 29A (A10,*)

(1) HL(1: 10)="region" :

The identification word for track length, nuclide yield and heat deposition tally. This word should be entered in the column between 1 and 10.

(2) NTREG (= NYREG = NHREG) :

The number of regions for track length, nuclide yield and heat deposition tally are set. If NTREG is zero, the whole body of the problem is selected for the tally so that the cards 29B and 29C are omitted.

CARD 29B (A10,*) [NTREG > 0]

(1) HL(1: 10) = "region" , (fixed word).

(2) KTREG(1: NTREG) = (KYREG(1: NYREG) = KHREG(1: NYREG)) :

The region number where track length tally, nuclide yield tally and heat deposition tally are set.

CARD 29C (A10, *) [NTREG < 0]

(1) HL(1: 10) = "region" (fixed word).

(2) KREG1 : The first region where track length tally, nuclide yield tally and heat deposition tally are set.

(3) KREG2 : The last region where track length tally, nuclide yield tally and heat deposition tally are set.

Note : The card 29 can be accompanied with the cards 30 to 32.

CARD 30A (A10,*) : If the nuclide yield tally is not used, the card 30A is omitted.

(1) HL(1: 10)="y-region" (fixed word).

The identification word for nuclide yield tally. The word should be entered in the column between 1 and 10.

(2) NYREG : The number of regions where nuclide yield tally is set. In the case of NYREG is zero, nuclide yield tally is set to all regions defined by the geometry input card so that the following cards 30B and 30C should be omitted.

CARD 30B (A10, *) [NYREG > 0]

(1) HL(1: 10)="y-region" (fixed word).

(2) KYREG(1: NYREG) :

Region number for nuclide yield tally.

CARD 30C (A10, *) [NYREG < 0]

(1) HL(1: 10)="y-region" (fixed word).

(2) KREG1 : The starting region number for nuclide yield tally.

(3) KREG2 : The ending region number for nuclide yield tally. According to this entry, the value of NYREG is reset as KREG2-KREG1+1.

CARD 31A (A10, *) : If the heat deposition tally is not used, the card 31A is omitted.

(1) HL(1: 10)="h-region" (fixed word).

The identification word for heat deposition tally. The word should be entered in the column between 1 and 10.

(2) NHREG : The number of regions where heat deposition tally is set. In the case of NHREG is zero, heat deposition tally is set to all the regions defined by the geometry input card so that the following cards 31B and 31C should be omitted.

CARD 31B (A10, *) [NHREG > 0]

(1) HL(1: 10)="h-region" (fixed word).

(2) KHREG(1: NHREG) :

Region number for heat deposition tally.

CARD 31C (A10, *) [NHREG < 0]

(1) HL(1: 10)="h-region" (fixed word).

(2) KREG1 : The starting region number for heat deposition tally.

(3) KREG2 : The ending region number for heat deposition tally. According to this entry, the value of NHREG is reset as KREG2-KREG1+1.

CARD 32A (A10, *) : If the track length tally is not used, the card 32A is omitted.

(1) HL(1: 10)="t-region" (fixed word).

The identification word for track length tally. The word should be entered in the column between 1 and 10.

(2) NTREG : The number of regions where track length tally is set. In the case of NTREG is zero, track length tally is set to all the regions defined by the geometry input card so that the following cards 32B and 32C should be omitted.

CARD 32B (A10, *) [NTREG > 0]

(1) HL(1: 10)="t-region" (fixed word).

(2) KHREG(1: NHREG) :

Region number for track length tally.

CARD 32C (A10, *) [NTREG < 0]

(1) HL(1: 10)="t-region" (fixed word).

(2) KREG1 : The starting region number for track length tally.

(3) KREG2 : The ending region number for track length tally. According to this entry, the value of NTREG is reset as KREG2-KREG1+1.

CARD 33 (A10, *)

(1) HL(1: 10)="sp-unit" (fixed word).

The identification word for unit of particle spectra obtained by track length, surface crossing spectrum and surface crossing flux tallies. This word should be entered in the column between 1 and 10.

(2) KSUNIT : Option for the unit of particle spectra obtained by track length, surface crossing spectrum and surface crossing flux tallies. The default value is 0.

= 0 : [1/cm^2/group/source].

= 1 : [1/cm^2/MeV/source].

= 2 : [1/cm^2/lethargy/source].

CARD 34 (A10, *)

(1) HL(1: 10)="pt-surf" (fixed word).

The identification word for particle type obtained by the surface crossing tallies. This word should be entered in the column between 1 and 10.

(2) KPSURF : Option for the particle type scored by the surface crossing tallies. The default value is 3.

= 2 : neutron and proton.

= 3 : neutron, proton and sum of pions.

= 5 : neutron, proton, π^+ , π^0 and π^-.

7.3 Execution of Calculation

On the UNIX system, it is convenient to use a "make" command for making an execution module of a source program. Figure B-2 of Appendix B shows an example of a "makefile" shell script file for compiling the source program and linking the object modules. The NMTC/JAERI97 code uses several logical units for both the data input and output. The following logical units should be assigned for input data:

Logical unit 5 : Input data for NMTC/JAERI97.

Logical unit 21 : Nuclear structure data and cross section data of elemental nucleon-nucleon and nucleon-pion reactions.

Logical unit 30 : Level density parameter derived by Baba.

It is recommended that the user assigns certain names to the output files made through the individual logical unit although the default name with the logical unit number is assigned implicitly by the UNIX system even if any file name is not given on the logical unit. The code includes a program to assign file name to a logical unit in a specified manner. An example of a batch file to execute the code is shown in Fig. B-3 of Appendix B. Here, the files relevant to the input data have to be assigned on the logical units 21 and 30 as described above. The history file of cut-off neutrons is produced in the directory on which the code runs.

7.4 Data Format of Output Files

(1) History File for Cut-off Neutrons

When the energy of a travelling or produced neutron becomes lower than the cut-off energy, the information about position, energy and weight are stored in a history file with the binary format through the logical unit 12. The data format of cut-off neutrons in the history file is shown in Fig. C-1 of Appendix C. As described in Section 2.1, NMTC/JAERI97 assumes the use of the code MCNP4A[12)] for the transport calculation of cut-off neutrons. It is required to prepare a user-supplied source routine in MCNP4A to read the information of the cut-off neutrons. The program of the user supplied source routine is listed in Fig. C-2 of Appendix C.

(2) Output File for a Summary of Calculation

The summary of a calculation is printed out to a standard output file assigned to the logical unit 6. An example of an output file for summary of a calculation is shown in Fig. B-5 of Appendix B. The information included in the output file are as follows.

- ·Input data, physics models and data used in the calculation.
- ·Input nuclides and their number densities in target materials.
- ·Input data for geometry of the problem. (Those are eliminated from this example.)
- ·Importance values given to individual region.
- ·Input data for the incident particle beam configuration.
- ·Input data for tallies such as energy bin information, volume of each region, region boundary and region number given for tally.
- ·Energy, coordinate points, directional cosines, weight and type of source particles up to 25 particles from the first one.
- ·Summary data of each batch, i.e. elapsed cpu time, warning messages, the number of produced neutrons, final random number.
- ·Summary of particle production rate every after 10 batches.
- ·Results of importance sampling region by region.
- ·Overall summary of the Monte Carlo calculation such as the next initial random number, total number of cut-off neutrons, total weights of cut-off neutrons, average weight per source and the elapsed cpu time.

(3) Output Files for Tallies

NMTC/JAERI97 produces 13 output files at maximum for tallies. The logical unit number assigned to individual tally is summarized in Table B-1 of Appendix B. The examples of output files for the tallies are shown in Figs. B-6 to B-11. In the output file for the track length tally, the calculated results are listed in 5 columns as seen in Fig. B-6. The first column lists the region number in increasing order. The second and third columns show the calculated neutron flux per source particle and its relative error. The unit of flux is defined in the input CARD 33-(2). The relative statistical error of flux is obtained by the eq. (29). The forth and the last columns are for calculated proton flux and its relative error.

The output files for the surface crossing current spectrum and the surface crossing flux spectrum tallies have the same data format as shown in Figs. B-7 and 8 . The first column lists the upper boundary value of an energy bin in increasing order. The surface crossing current spectrum value or the surface crossing flux spectrum is given in the second column followed by its relative statistical error in the next column. The pair of the current spectrum or flux spectrum and the relative statistical error is repeated at every boundaries where the tally is set .

Figure B-9 shows the example of an output file for the surface crossing current tally. The axial boundary value is printed out at first on this file. Then, the lower and upper radial boundary values are written in the first column. The surface crossing current per source particle and its relative statistical error at the radial bin are listed. The lists of the surface crossing current and its relative statistical error are repeatedly printed out for every particles selected in the input card.

For the output file of the nuclide yield tally, the nuclide yield per source particle is printed out region by region in increasing order of atomic number from hydrogen (See Fig. B-10). For each element, the nuclide yield are calculated for 48 isotopes at maximum and printed out in increasing order of the mass number from the second column. The mass number is written on the second line.

The example of an output file of the heat deposition tally is shown in Fig. B-11. This output file shows the total amount of heat deposition and its components region by region in the unit of MeV/cm^3 per incident particle. The output of heat deposition by the charged particles is classified to 4 components with the titles of "fission", "reaction", "cut-off" and " slow-down". These titles mean the energy losses of the charged particles (deuteron, triton, He-3 and α-particle) emitted from fission fragment, the charged particles emitted from the evaporation of residual nuclei except fission fragment, the particles of proton, pion and muons which reached the cut-off value during the transport process and those in the slowing-down process in a medium, respectively. The sum of these 4 components is listed as "particle total" with a relative statistical error. The notation "fragment" in the next column represents the energy deposition of fission fragments produced by the high energy fission process. The "recoil" indicates the energy deposition by nuclei recoiled by elastic scattering and particle emission in the evaporation process. The total amount of heat deposition is obtained by the sum of the energy loss of charged particles denoted as "particle total", fission fragments and recoiled nuclei, and the value is listed in the last column with a relative statistical error. As is instructed in the Table B-1 of Appendix B, the details of each components are listed on the output files through the logical unit from 56 to 61 with a manner similar to this example.

7.5 Memory Management and Error Messages

The total size of memory used for the arrays in the code is defined in the bulk array "das" with a variable "ldasmax" in the parameter block file "PARM" in the INCLUDE directory.

Since 10,000 of ldasmax is used for sorting the input data and the remainder is assigned to the array size used for tallies, it is required that the additional memory 10,000 should be added to the value for the initial value of "ldasmax". As described above, the memory size can be checked on the output file (see Fig. B-5). The value marked with the word "used" indicates the memory required for data storage for the tally and that with the word "extra" indicates the memory size not used in the calculation. In the case that the memory lacks, the calculation is terminated and an error message is printed out.

As far as the program error is concerned, the message number from 801 to 843 is assigned to individual abnormal termination processes in the code. If any error happens in any subroutine during the computation, the program is terminated and then the error number is written out on an output file with a certain error message and the name of subroutine.

8. Summary

The upgraded version of the nucleon-meson transport code NMTC/JAERI-97 was developed by supplementing some new nuclear reaction models and replacing the old nuclear data into the preceding NMTC/JAERI. In order to improve the accuracy of the nuclear reaction calculation, especially in the energy region below 200 MeV, the ISOBAR code taking account of the in-medium nuclear effects was implemented as an alternative option for the intranuclear cascade calculation. The preequilibrium calculation model based on the exciton one was also introduced so that the nuclear reactions could be simulated with the Bertini, the present preequilibrium and the evaporation models. For treating the nucleon transport process more accurately, the old nucleon-nucleus cross sections independent of the incident energy were replaced with those derived by the systematics of Pearlstein. Moreover, the level density parameter options for particle evaporation calculation were supplemented by including the formula of Ignatyuk.

In addition to the implementation of these physics models, tally functions and importance sampling technique for transport calculation were newly installed in the code. The new geometry package based on the Combinatorial Geometry with multi-array system, MARS, was also introduced to treat a complex three dimensional geometry easily. In this upgrade, the code was also tuned to be executed on the UNIX system. Due to the implementation of these new calculational functions, consequently, NMTC/JAERI97 will enable us to carry out neutronics design of a large scale target system with complex geometry more accurately and easily than before.

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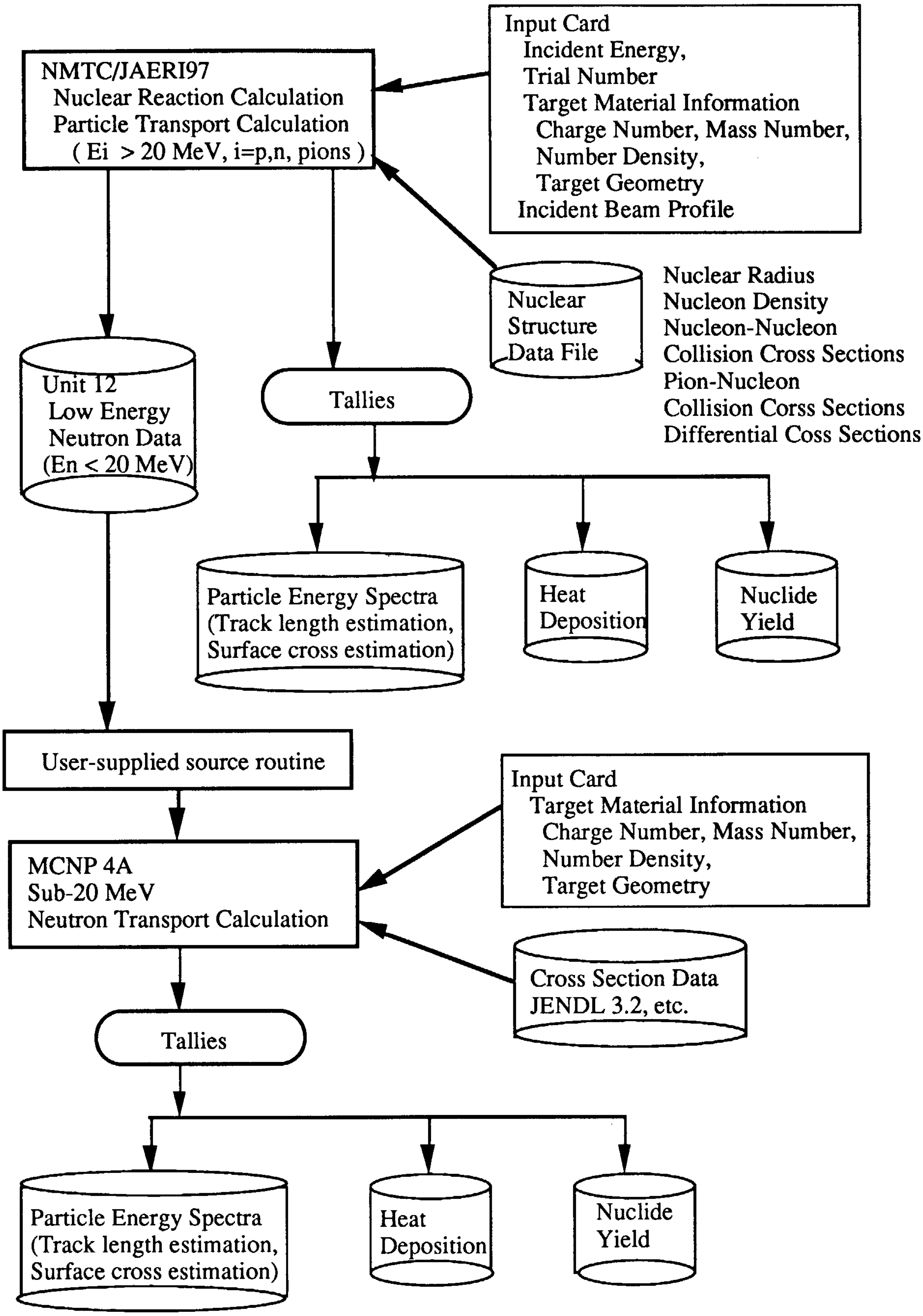


Fig. 1 Flow of neutronics calculation with the NMTC/JAERI97 and MCNP4A code.

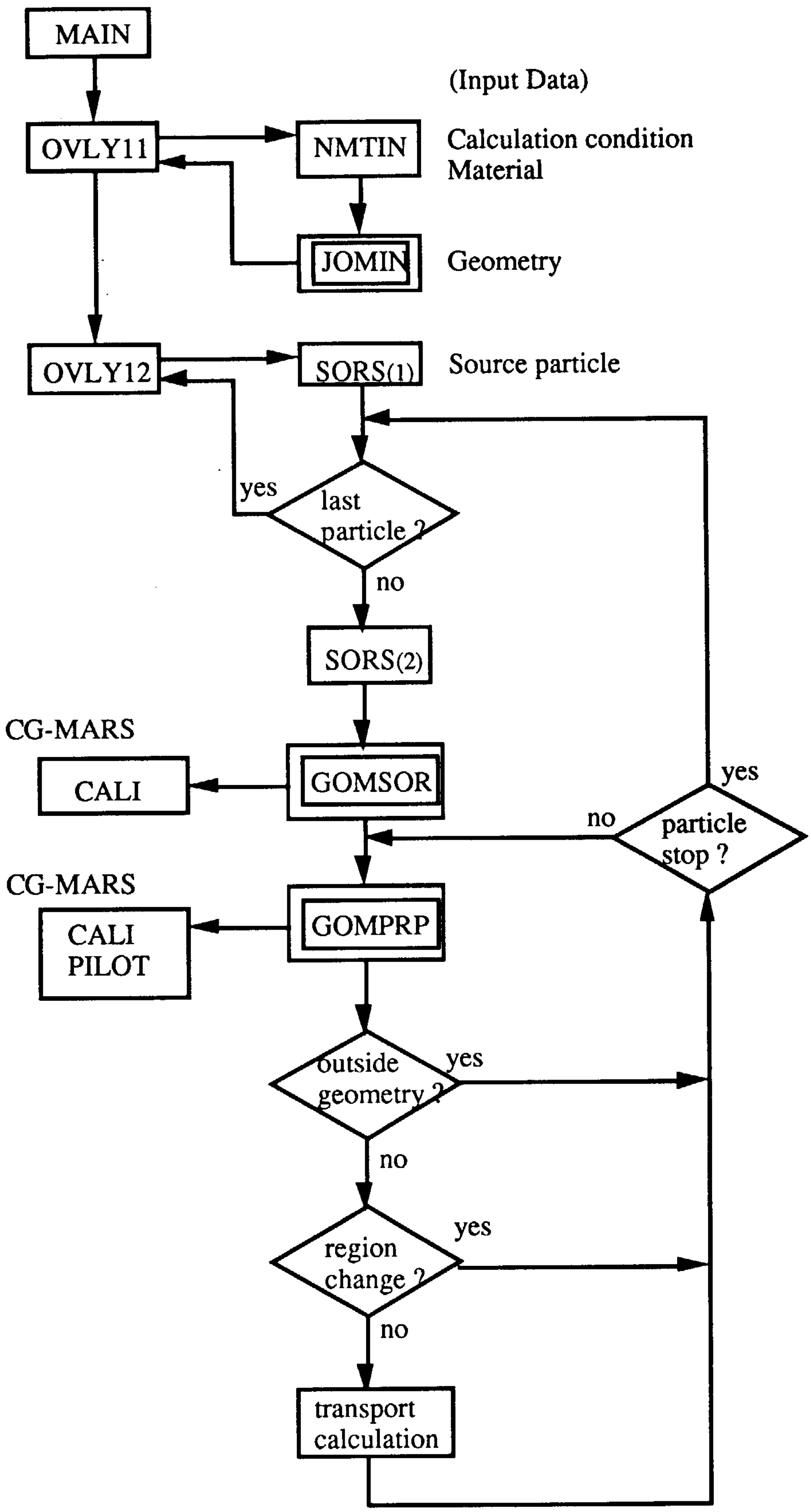


Fig. 2 Calculation flow for checking the position of a particle in NMTC/JAERI97.

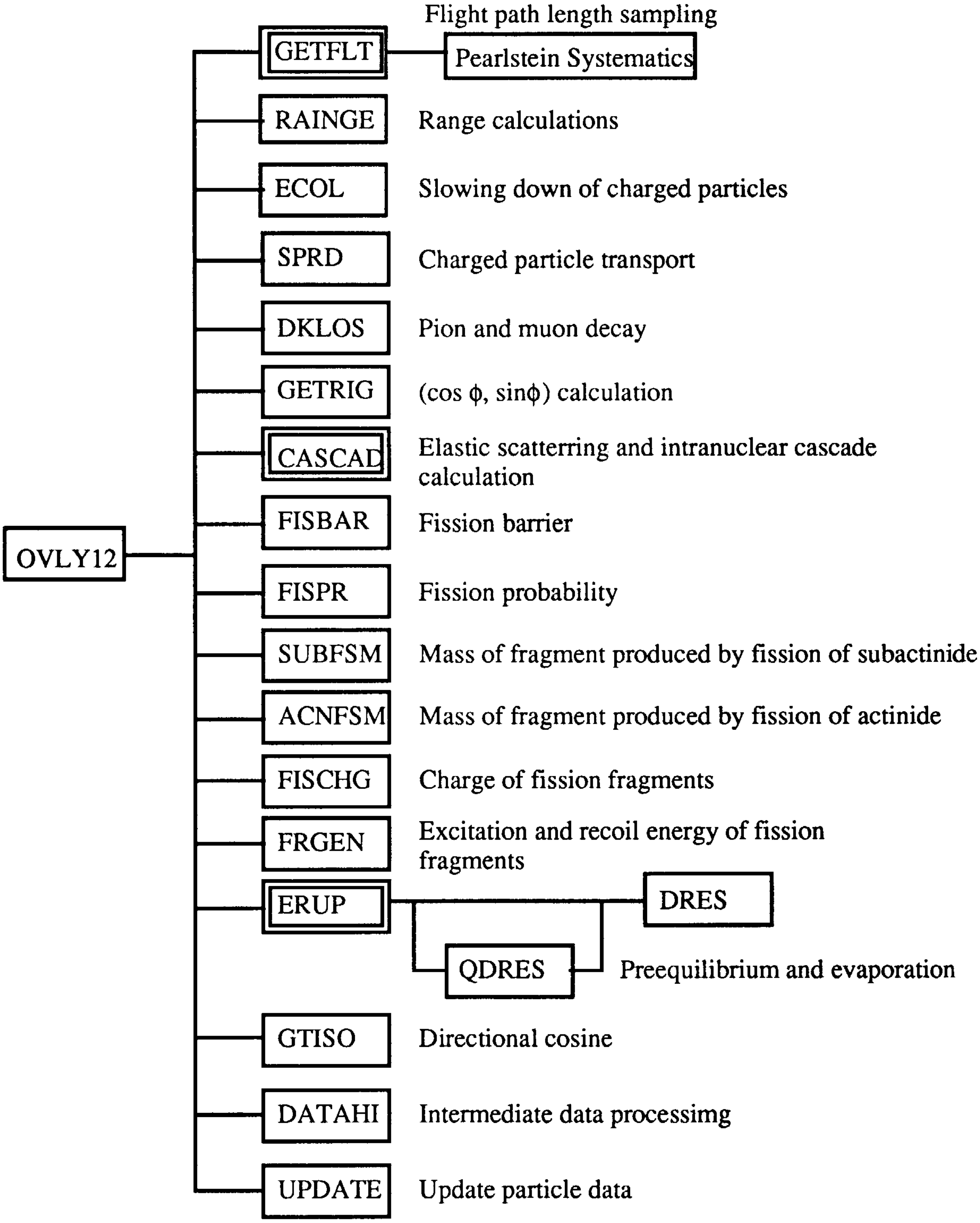


Fig. 3 Major subroutines and their function for forming the subroutine OVLY12 in NMTC/JAERI97 . The double frame box means that the subroutine has been revised in the present work.

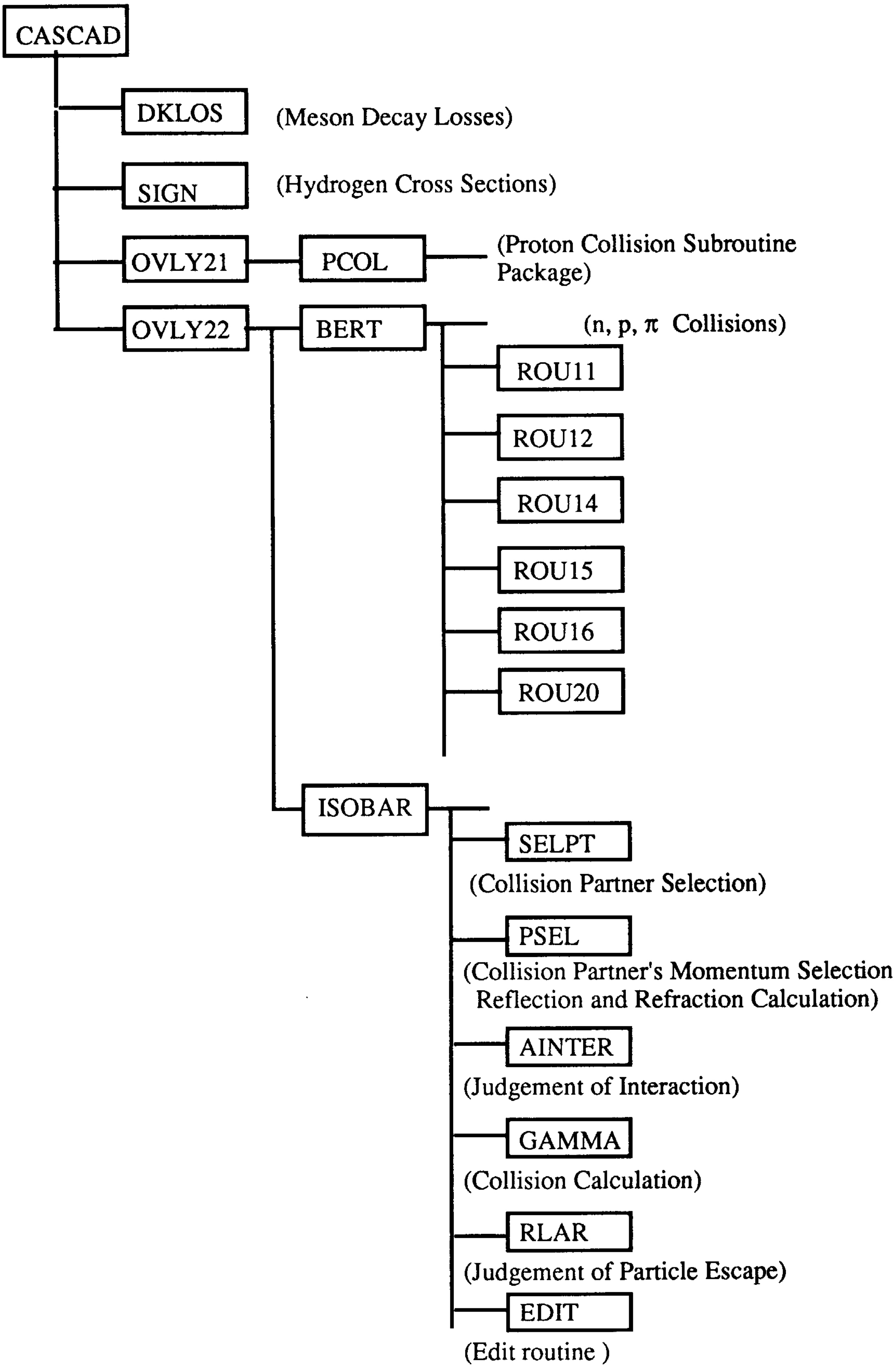


Fig. 4 Major subroutines and their functions in the intranuclear cascade calculation with the Bertini model and the ISOBAR code in NMTC/JAERI97.

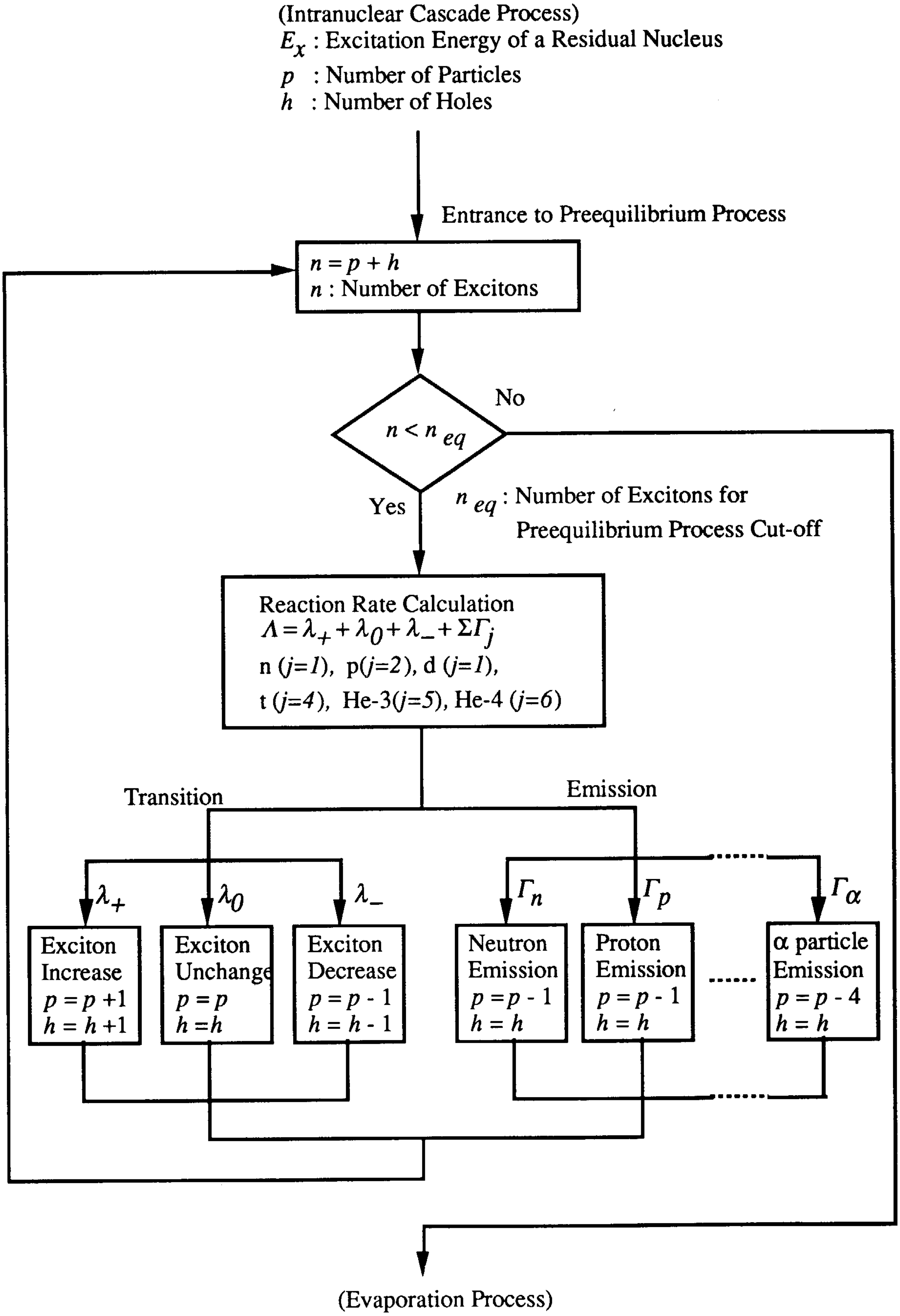


Fig. 5 Calculation flow for analyzing the preequilibrium process in NMTC/JAERI97.

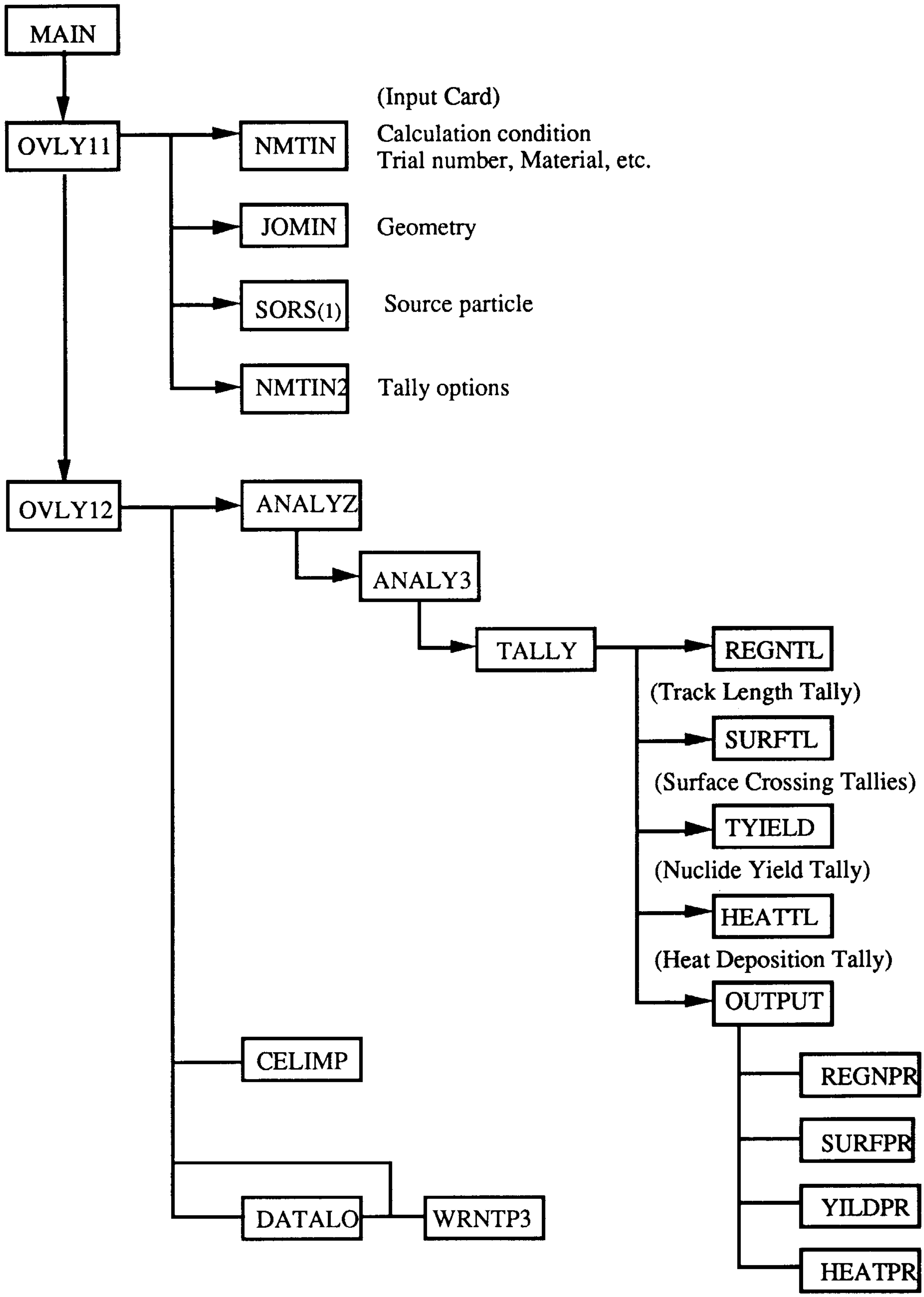


Fig. 6 Program tree of tally function in the NMTC/JAERI97 code.

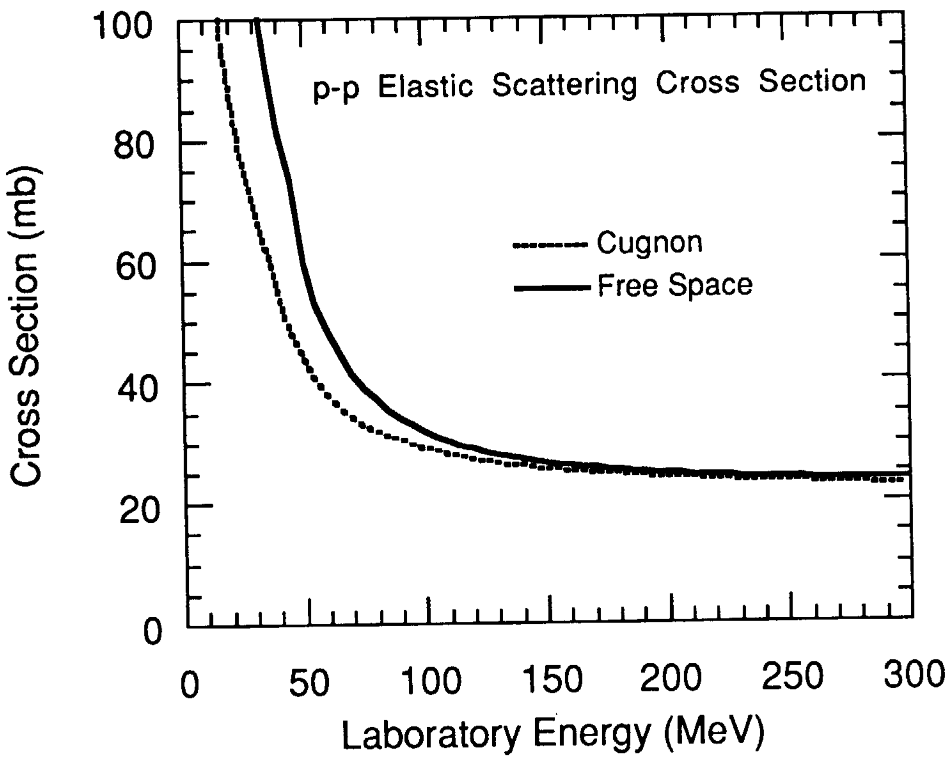


Fig. 7(a) Elastic scattering cross section for p-p collision. The solid and dotted lines indicate the cross sections in the free space and those obtaind by the Cugnon parametrization [22, 24,25], respectively.

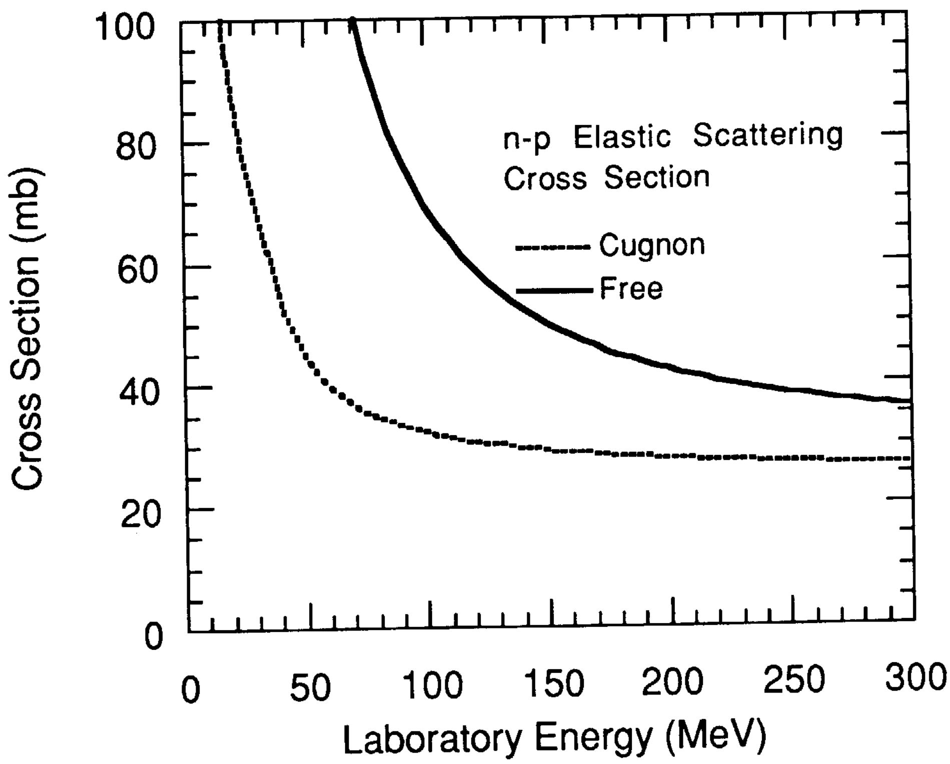


Fig. 7(b) Elastic scattering cross section for n-p collision. The notes to the lines are the same as for Fig. 7(a).

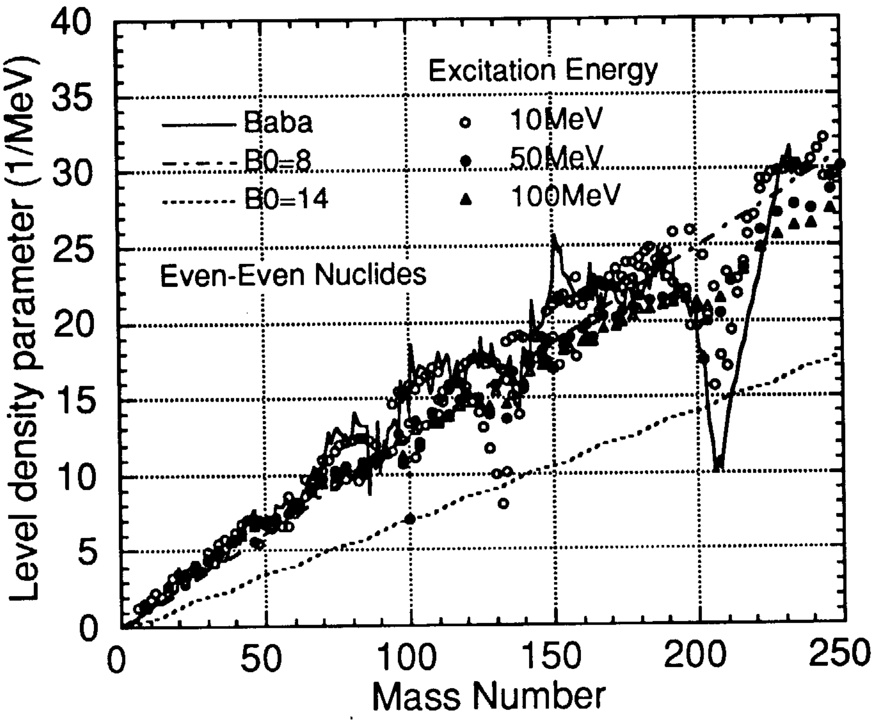


Fig. 8(a) Comparison of level density parameters for even-even nuclides. The solid, dot-dashed and dotted lines indicate the level density parameter compiled by Baba [32], that given by $A/8$ and $A/14$ with mass number A, respectively. The open circle, solid circle and open triangle stand for the parameters derived by the Ignatyk's formula [33] at excutation energies of 10, 50 and 100 MeV, respectively.

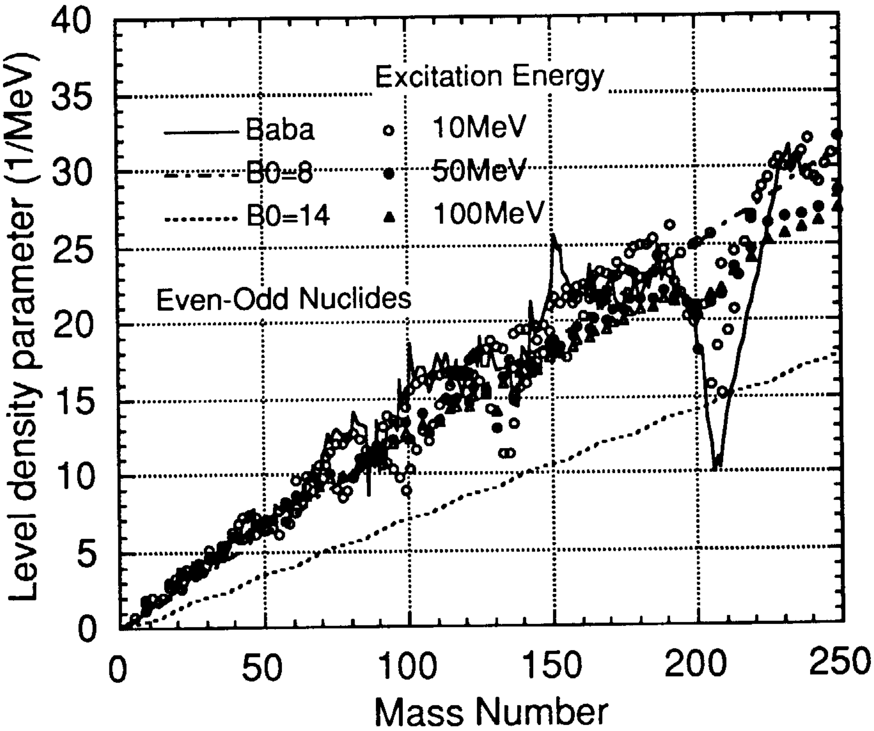


Fig. 8(b) Comparison of level density parameters for even-odd nuclides. The notes to the lines and marks are the same as for Fig. 8(a).

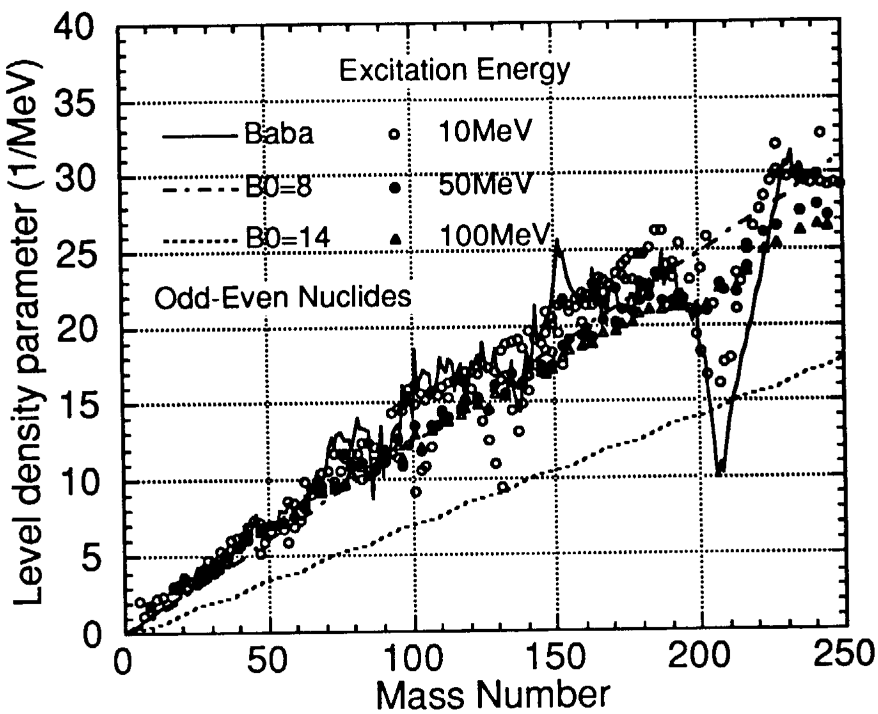


Fig. 8(c) Comparison of level density parameters for odd-even nuclides. The notes to the lines and marks are the same as for Fig. 8(a).

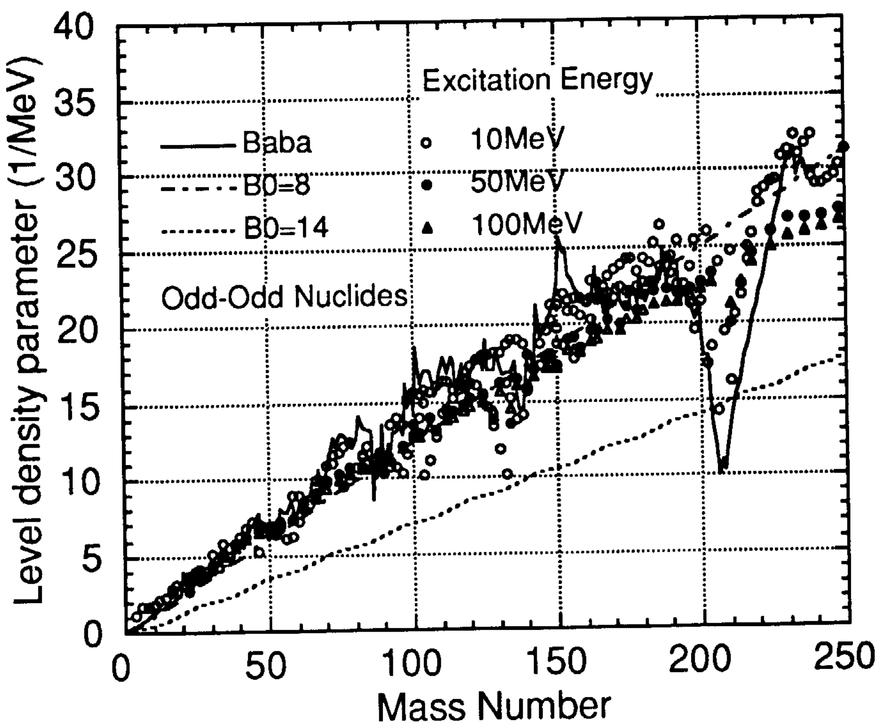


Fig. 8(d) Comparison of level density parameters for odd-odd nuclides. The notes to the lines and marks are the same as for Fig. 8(a).

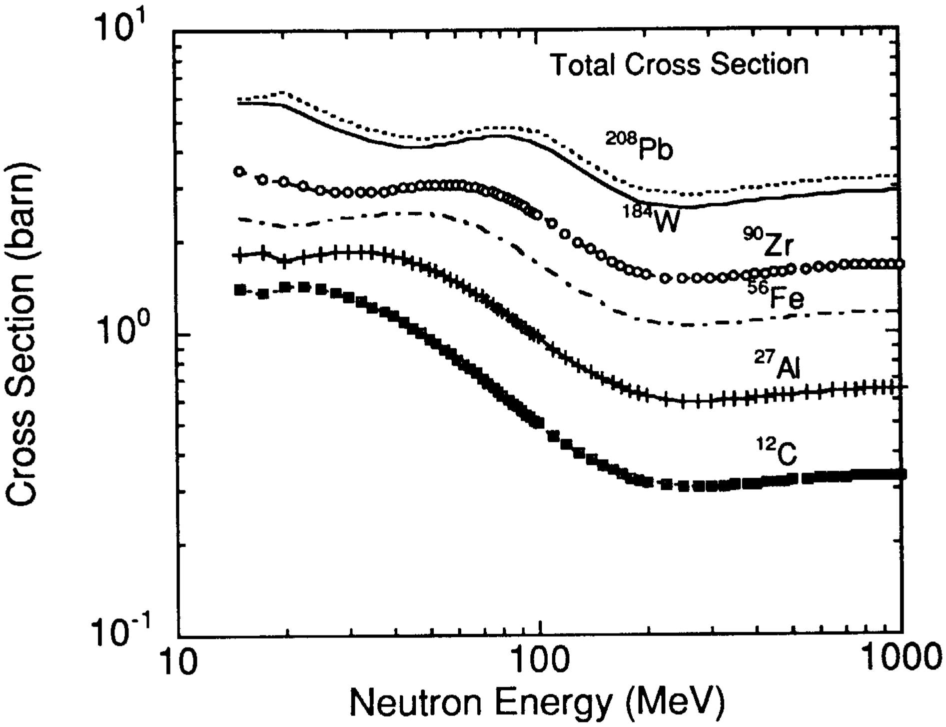


Fig. 9(a) Neutron total cross sections calculated with the systemtics of Pearlstein[8)] for ^{12}C, ^{27}Al, ^{56}Fe, ^{90}Zr ^{184}W and ^{208}Pb.

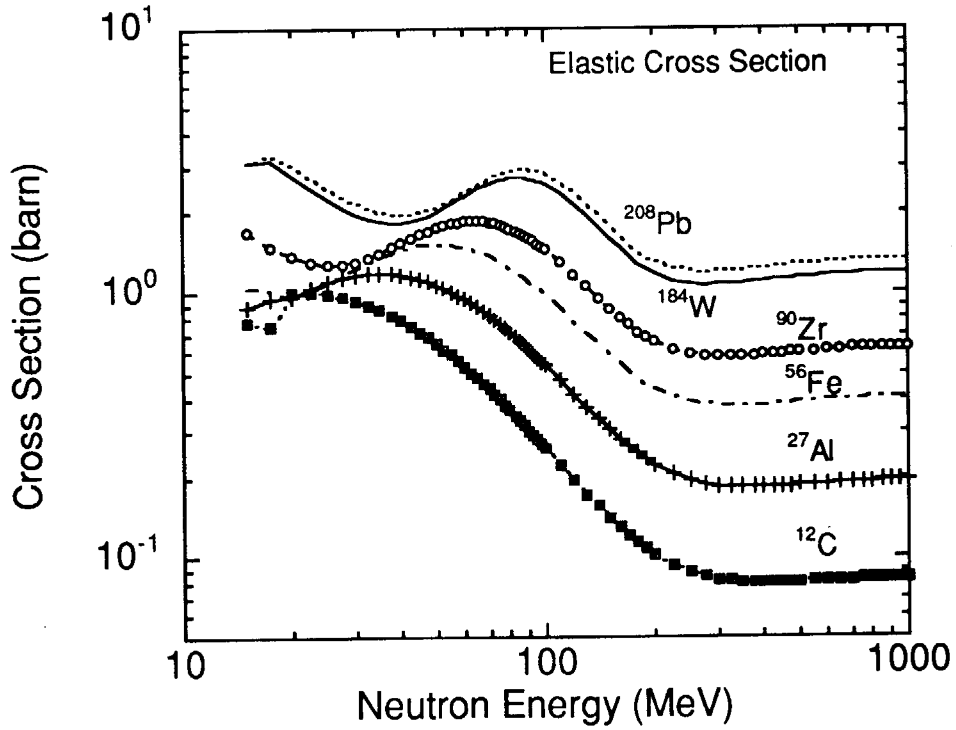


Fig. 9(b) Neutron elastic scattering cross sections calculated with the systemtics of Pearlstein[8)] for ^{12}C, ^{27}Al, ^{56}Fe, ^{90}Zr ^{184}W and ^{208}Pb.

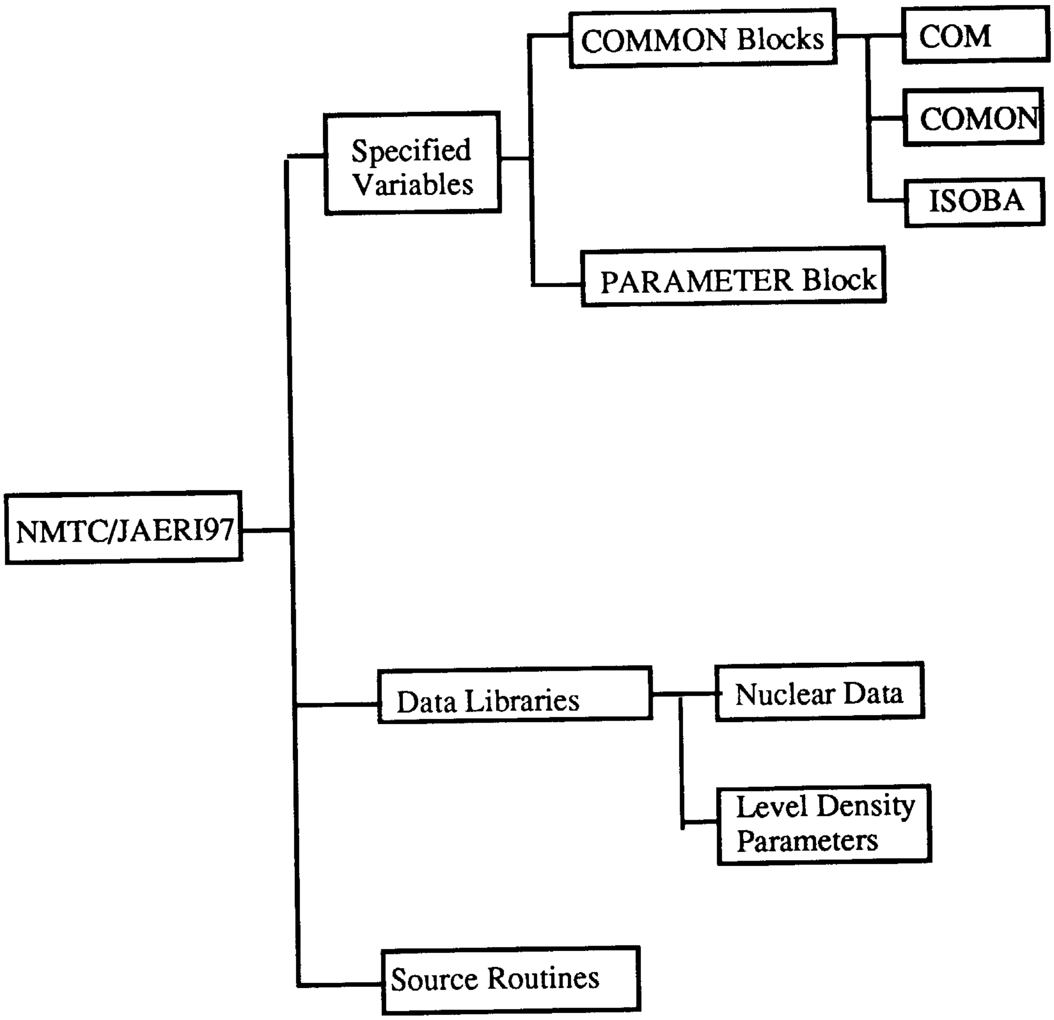


Fig. 10 Directory Structure of the NMTC/JAERI97 code.

Appendix A

Guide to Body Data Description for MARS in NMTC/JAERI97

Table A-1 Body configuration data for MARS.

Body Type	ITYPE	IALP*	Real Data Defining Particular Body					
Right Parallelepiped	RPP		X_{min}	X_{max}	Y_{min}	Y_{max}	Z_{min}	Z_{max}
Sphere	SPH		V_x	V_y	V_z	R		
Right Circular Cylinder	RCC		V_x	V_y	V_z	H_x	H_y	H_z
			R					
Right Elliptic Cylinder	REC		V_x	V_y	V_z	H_x	H_y	H_z
			R_{1x}	R_{1y}	R_{1z}	R_{2x}	R_{2y}	R_{2z}
Truncated Right Cone	TRC		V_x	V_y	V_z	H_x	H_y	H_z
			R_1	R_2				
Ellipsoid	ELL		V_{1x}	V_{1y}	V_{1z}	V_{2x}	V_{2y}	V_{2z}
			R					
Right Angle Wedge	WED		V_x	V_y	V_z	H_{1x}	H_{1y}	H_{1z}
			H_{2x}	H_{2y}	H_{2z}	H_{3x}	H_{3y}	H_{3z}
Box	BOX		V_x	V_y	V_z	H_{1x}	H_{1y}	H_{1z}
			H_{2x}	H_{2y}	H_{2z}	H_{3x}	H_{3y}	H_{3z}
Arbitrary Polyhedron	ARB		V_{1x}	V_{1y}	V_{1z}	V_{2x}	V_{2y}	V_{2z}
			V_{3x}	V_{3y}	V_{3z}	V_{4x}	V_{4y}	V_{4z}
			V_{5x}	V_{5y}	V_{5z}	V_{6x}	V_{6y}	V_{6z}
			V_{7x}	V_{7y}	V_{7z}	V_{8x}	V_{8y}	V_{8z}
			Number for Each Face (4 digits integer)					
Alternative Body	BPP		X_{min}	X_{max}	Y_{min}	Y_{max}	Z_{min}	Z_{max}
			θ_1	θ_2	θ_3			
Alternative Body	WPP		X_{min}	X_{max}	Y_{min}	Y_{max}	Z_{min}	Z_{max}
			θ_1	θ_2	θ_3			
General Ellipsoid	GEL		V_x	V_y	V_z	R_{1x}	R_{1y}	R_{1z}
			R_{2x}	R_{2y}	R_{2z}	R_{3x}	R_{3y}	R_{3z}
Truncated Right Elliptical	QUA		a	b	c	d	e	f
Cone			g	h	Z_1	Z_2		
Torus	TOR		X_0	Y_0	Z_0	R	a	b
			F_{xyz}	θ_1	θ_2			
End of Data	END							

* : IALP must be given if IBOD > 0 at the input card 11(2).

1. Right parallelepiped (RPP) :

RPP is defined by the minimum and maximum values of the x, y and z coordinates which bound the parallelepiped.

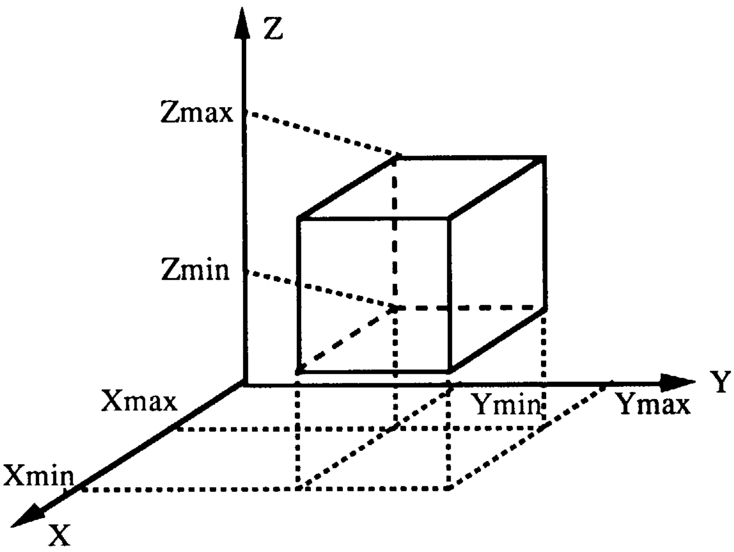


Fig. A-1 Illustration of a right parallelepiped (RPP).

2. Sphere (SPH) :

SPH is defined by the center point with the coordinates (V_x, V_y, V_z) and the radius R.

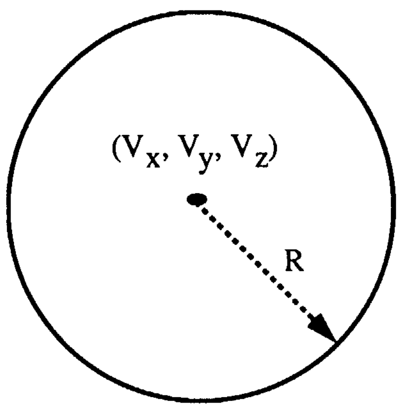


Fig. A-2 Illustration of a sphere (SPH).

3. Right circular cylinder (RCC) :

RCC is defined by the center coordinates (V_x, V_y, V_z) of the base circle with the radius, R, and the height vector with the component of (H_x, H_y, H_z).

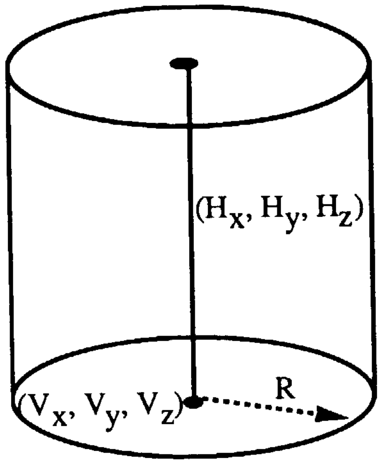


Fig. A-3 Illustration of a right circular cylinder (RCC).

4. Right elliptical cylinder (REC) :

REC is defined by the base ellipse and the height vector. The center coordinates of the ellipse, (V_x, V_y, V_z), the vector componets of the major and minor axes of the ellipse, (R_{1x}, R_{1y}, R_{1z}) and (R_{2x}, R_{2y}, R_{2z}), and the component of the height vector, (H_x, H_y, H_z).

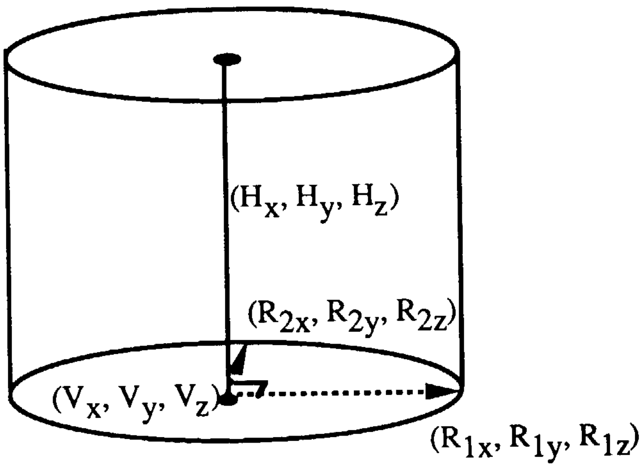


Fig. A-4 Illustration of a right elliptical cylinder (REC).

5. Truncated right angle cone (TRC) :

TRC is defined by the base and top circles with radii, R_1 and R_2 which intersect at right angles with the height vector with the component of (H_x, H_y, H_z) originated from the center coordinate of the base circle (V_x, V_y, V_z) ,

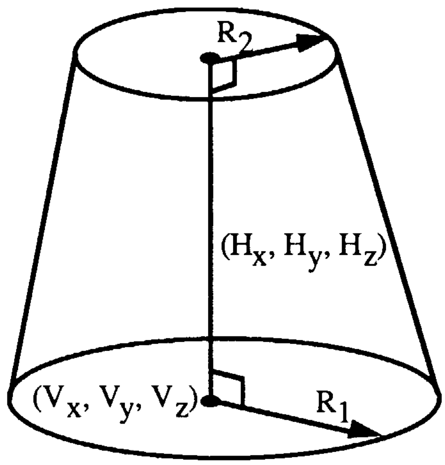


Fig. A-5 Illustration of a truncated right angle cone (TRC).

6. Ellipsoid (ELL) :

ELL is defined by the two center coordinates of the focii of vertices,(V_{1x}, V_{1y}, V_{1z}) and (V_{2x}, V_{2y}, V_{2z}), and the length of the major axis, R.

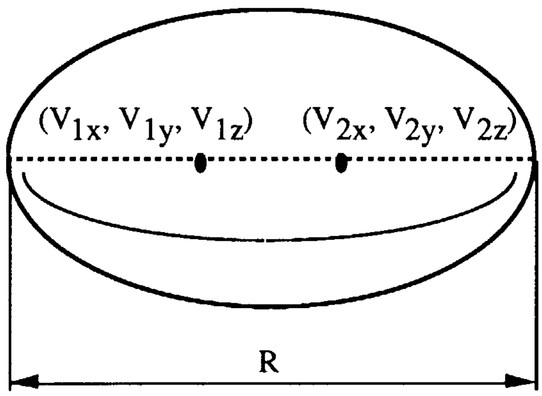


Fig. A-6 Illustration of an ellipsoid (ELL).

7. Right angle wedge (WED) :

WED is defined by one of the corners of the base angle wedge with the coordinates (V_x, V_y, V_z) and a set of mutually perpendicular three vectors. These vectors are determined by giving three coordinates of (H_{1x}, H_{1y}, H_{1z}), (H_{2x}, H_{2y}, H_{2z}) and (H_{3x}, H_{3y}, H_{3z}).

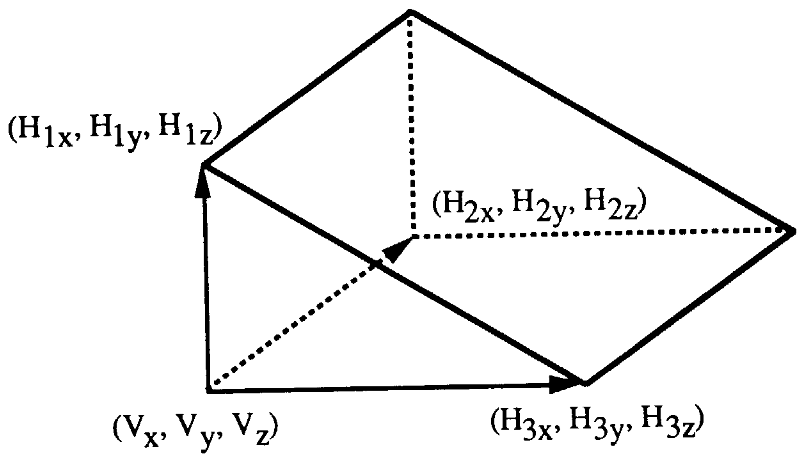


Fig. A-7 Illustration of a right angle wedge (WED).

8. Box (BOX) :

BOX is defined by the coordinates of one of the corners, (V_x, V_y, V_z), and a set of mutually perpendicular three vectors. These vectors are determined by giving three coordinates of (H_{1x}, H_{1y}, H_{1z}), (H_{2x}, H_{2y}, H_{2z}) and (H_{3x}, H_{3y}, H_{3z}).

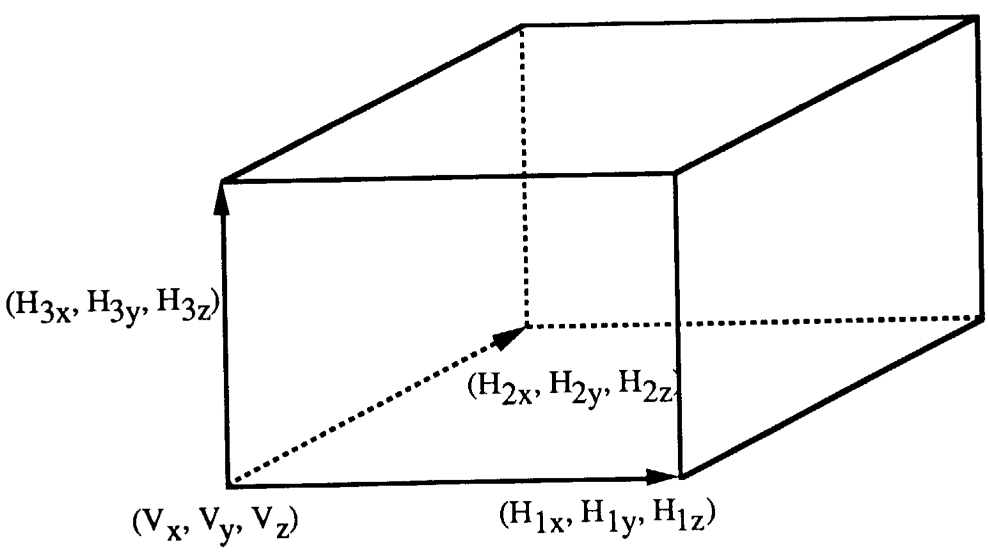


Fig. A-8 Illustration of a box (BOX).

9. Arbitrary polyhedron (ARB) :

ARB is defined by the coordinates of eight corners of the polyhedron from (V_{1x}, V_{1y}, V_{1z}) to (V_{8x}, V_{8y}, V_{8z}). Each of the six faces are described by a four-digits number, representing the four vertex points of the face. For each face, these indecies must be entered in either clockwise or counter-clockwise order.

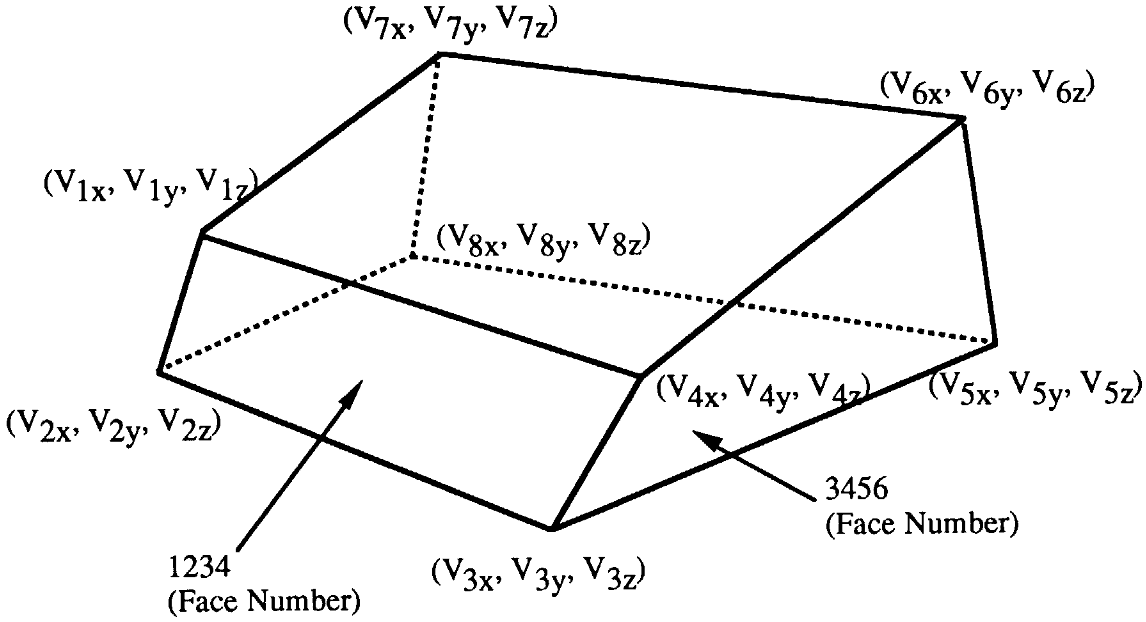


Fig. A-9 Illustration of an arbitrary polyhedron (ARB).

10. Alternative body description (BPP, WPP) :

BPP and WPP are bodies obtained by the rotation of the box and the right angle wedge with respect to the X, Y and Z axes. BPP is for the rotation of the box and WPP is for the right angle wedge, respectively. BPP and WPP require the user to describe rectanglar parallelepiped, similar to RPP, with three rotation angles. The first angle is for the first rotation of RPP which is the X-Y rotation about the Z axis and is positive in the clockwise direction (1st step). The second angle is a Y-Z rotation about the X axis and is positive in the clockwise direction (2nd step). The body rotated by the 1st step procedure is again rotated by the second angle in the 2nd step procedure. The third angle is a X-Z rotation about Y axis and is positive in the counter clockwise direction. Due to this procedure, the body rotated in the 2nd procedure is again rotated about Y axis by the third angle input. The above procedures are illustrated in the following Figure.

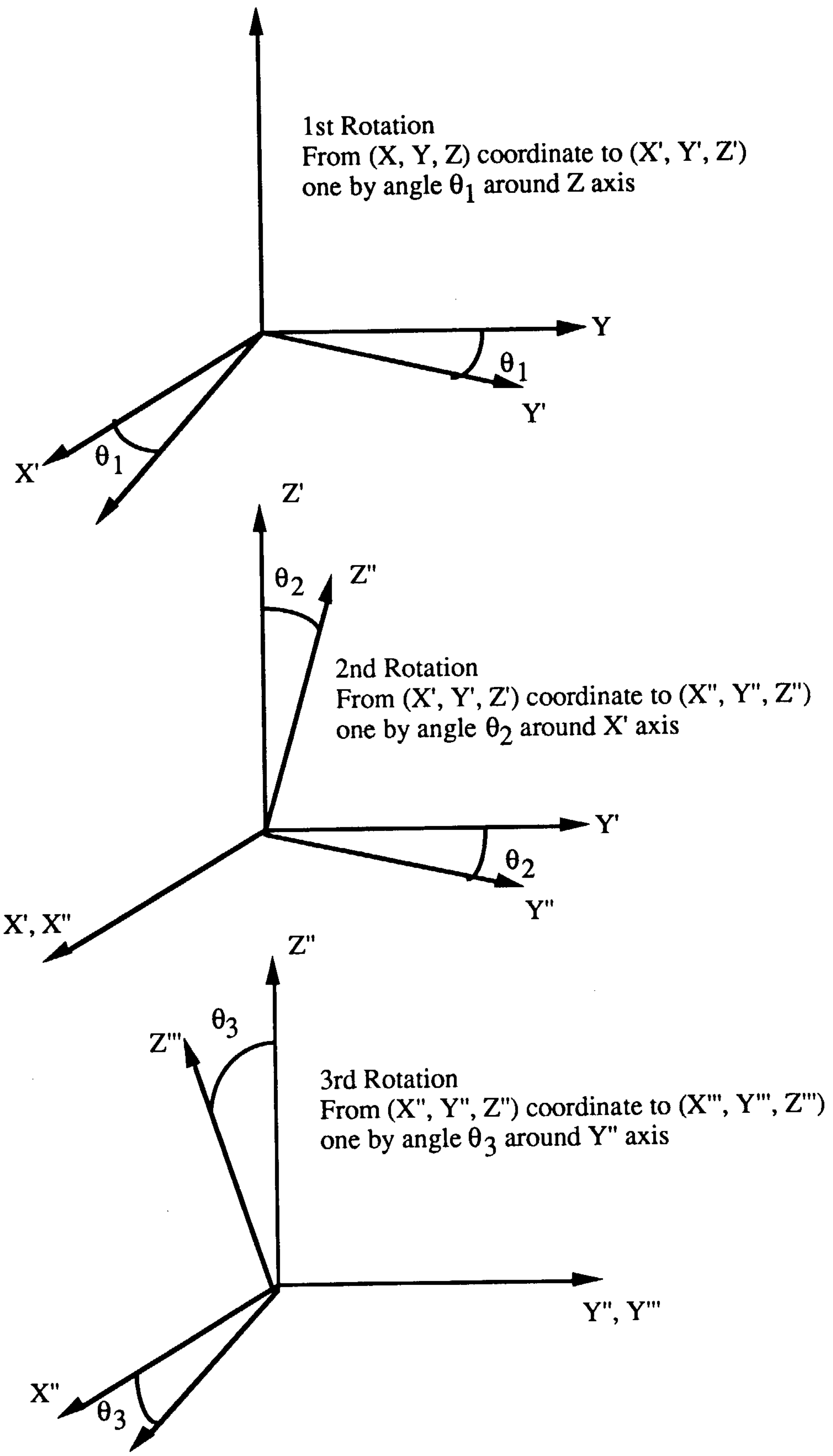


Fig. A-10 Illustration of the procedure to make an alternative body (BPP, WPP) from BOX or WED.

11. General ellipsoid (GEL) :

GEL is defined by the center coordinats of the ellipsoid, (V_x, V_y, V_z), the mutally perpendicular three vectors for the three radii with the components of (R_{1x}, R_{1y}, R_{1z}), (R_{2x}, R_{2y}, R_{2z}) and (R_{3x}, R_{3y}, R_{3z}).

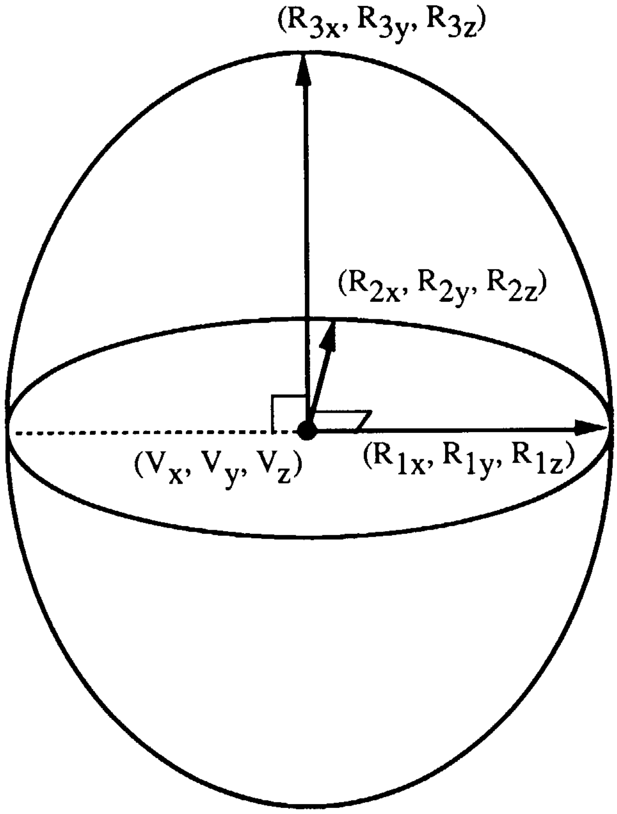


Fig. A-11 Illustration of a general ellipsoid (GEL).

12. Truncated right elliptic cone (QUA) :

QUA is defined by the two right ellipses parallel to the X-Y plane. The QUA is represented in the mathematical manner as follows.

$$(ax + by + cz)^2 + (dx + ez + f)^2 = (gz + h)^2$$

or

$$\left\{\frac{x + (bz+c)/a}{(gz+h)/a}\right\}^2 + \left\{\frac{y + (ez+f)/d}{(gz+h)/d}\right\}^2 = 1$$

Here, the distances beween the origin O and the centers of the two ellipses P and Q are given as:

$$\overrightarrow{OP} = \left(-\frac{bZ_1 + h}{a}, -\frac{eZ_1 + f}{d}, Z_1\right),$$
$$\overrightarrow{OQ} = \left(-\frac{bZ_2 + h}{a}, -\frac{eZ_2 + f}{d}, Z_2\right).$$

And, the half length of the major and minor axes of the two ellipses are given as:

$$(|PA|, |PB|) = \left(\frac{gZ_1 + h}{a}, -\frac{gZ_1 + h}{d}\right),$$
$$(|QA'|, |QB'|) = \left(\frac{gZ_2 + h}{a}, -\frac{gZ_2 + h}{d}\right).$$

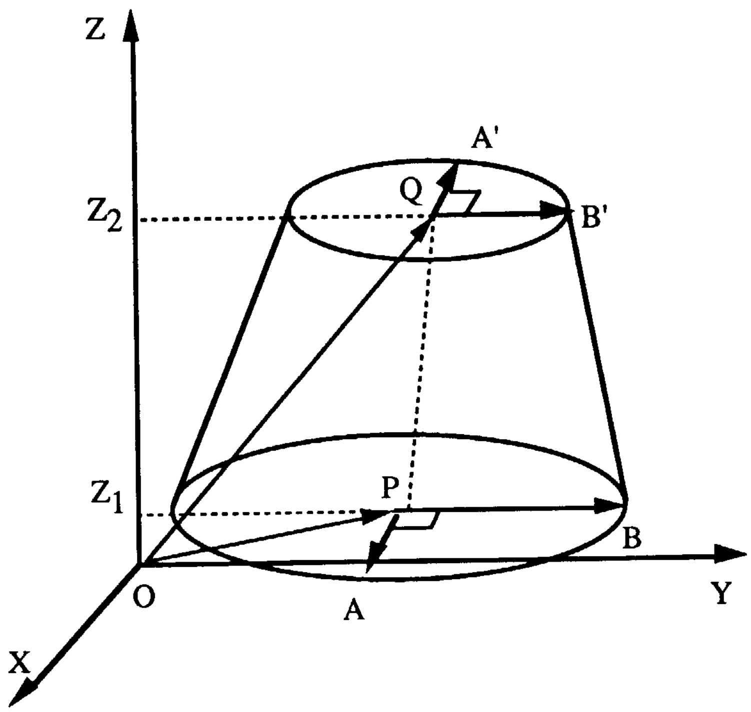
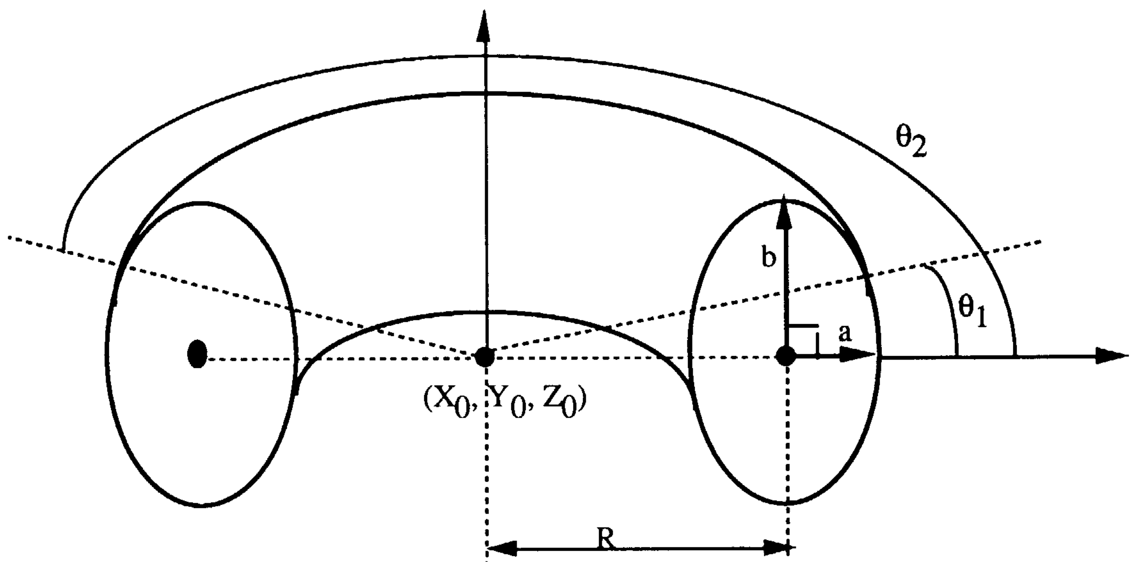


Fig. A-12 Illustration of a truncated right elliptical cone (QUA).

13. Torus (TOR) :

TOR is defined by the rotation of a right ellipse having its center apart from the origin (X_0, Y_0, Z_0) at the distance R. The values of the major and minor axes of the ellipse a and b are given as input data with the angles for the start and end of the rotation, θ_1 and θ_2, respectively. The center axis for the rotation is specified with a parameter F_{xyz} .



$F_{xyz} = 1$; θ_1 and θ_2 are the angles around X axis, in other words on the Y-Z plane.
$F_{xyz} = 2$; θ_1 and θ_2 are the angles around Y axis, in other words on the X-Z plane.
$F_{xyz} = 3$; θ_1 and θ_2 are the angles around Z axis, in other words on the X-Y plane.

Fig. A-13 Illustration of a torus (TOR).

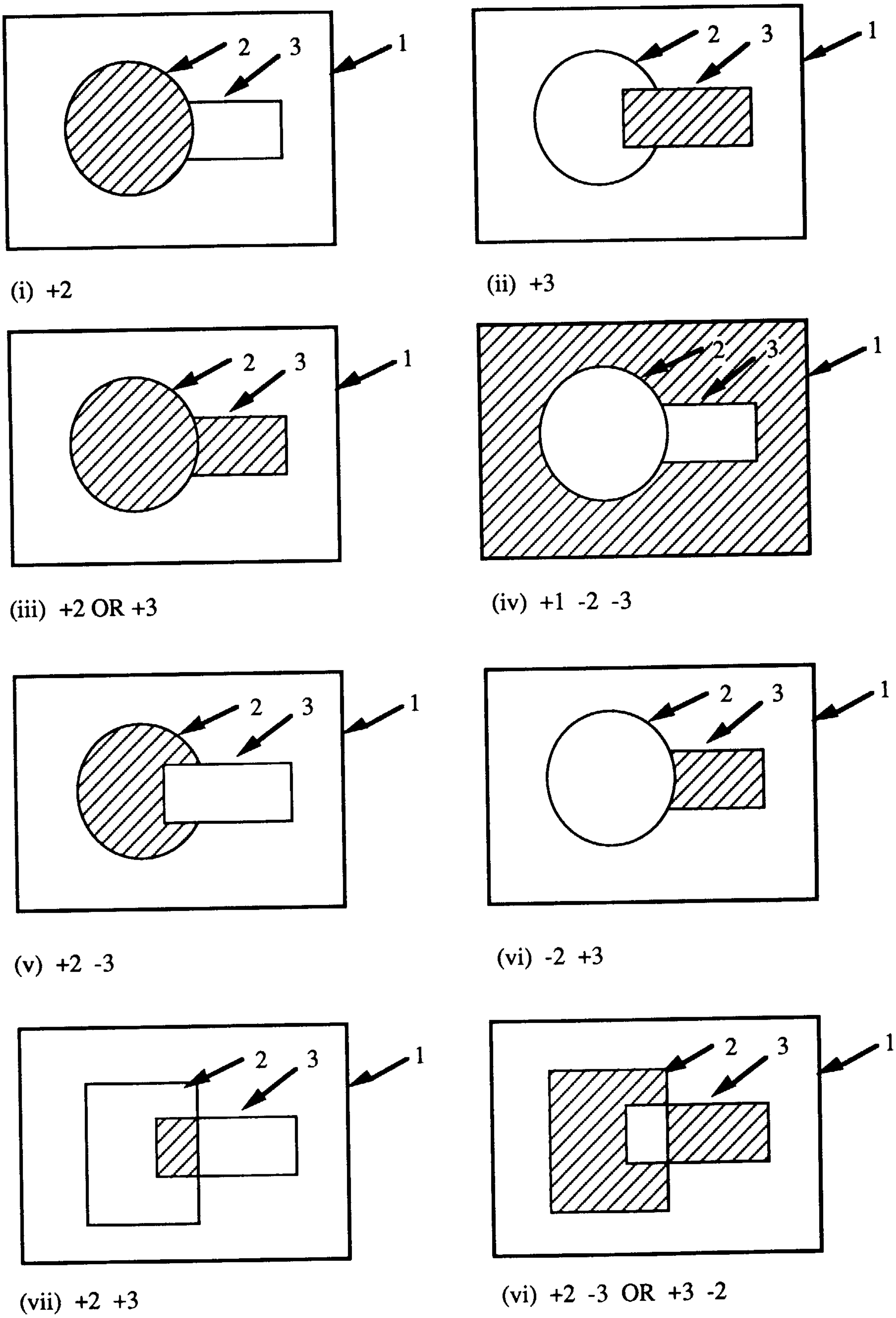


Fig. A-14 Examples of zone description with CG manner.

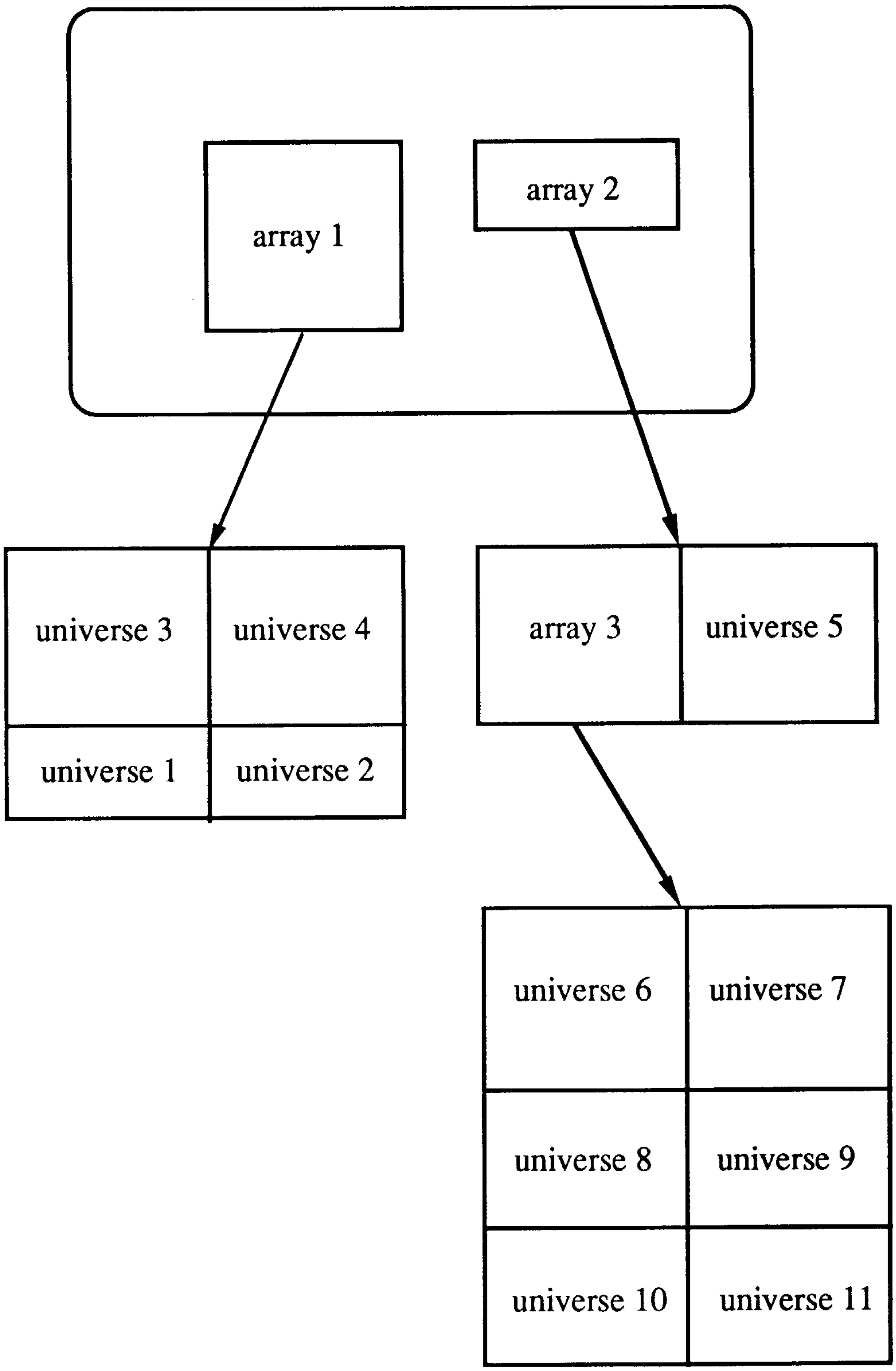
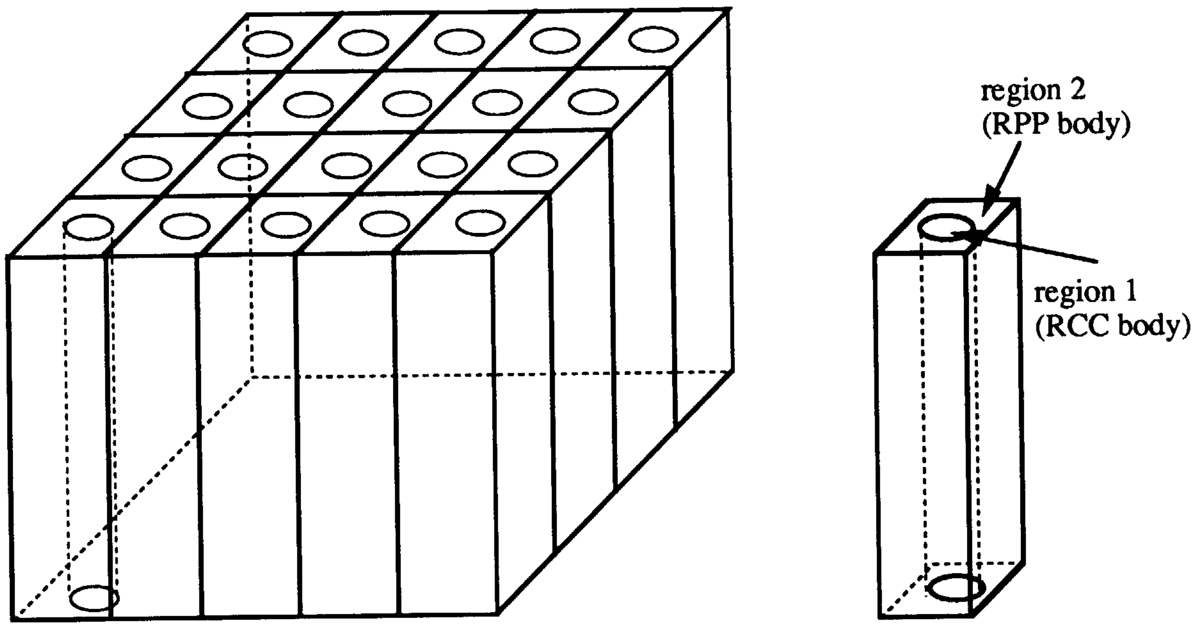
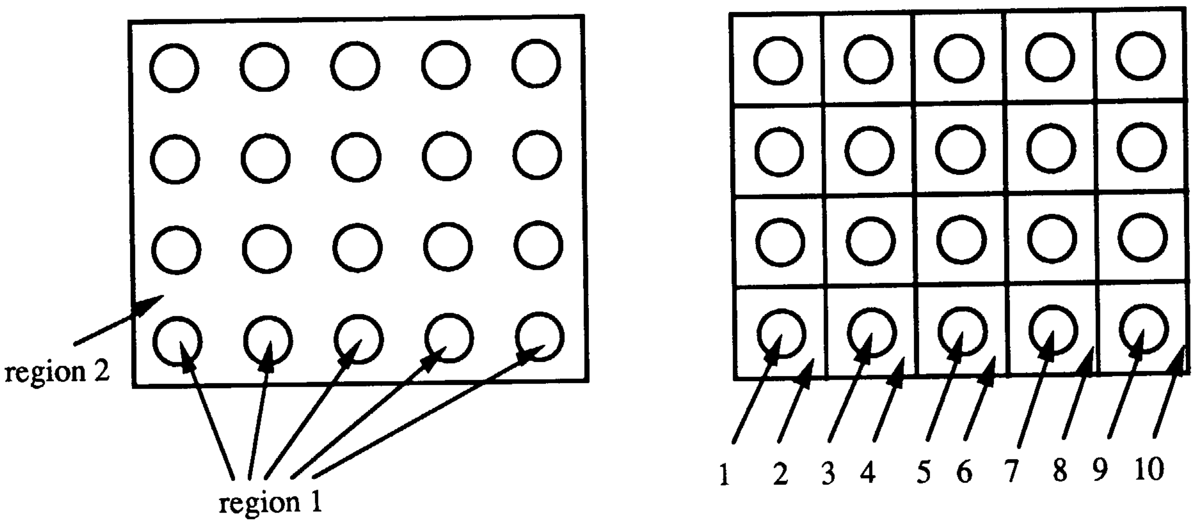


Fig. A-15 Relation between arrays and universes described by the geometry model MARS.



(a) Array

(b) Universe



(c) Region number assignment in case that an array is composed of single universe.

(d) Region number assignment in case that an array is composed of different universes.

Fig. A-16 Sample geometry configuration described using the concepts of array and universe.

```
array test model (not divide regions)
0  0   1  10
rcc 1   0.0  0.0  0.0   0.0  0.0 10.0   1.0
rpp 2  -2.0  2.0   -2.0  2.0   0.0 10.0
rpp 3   0.0  20.0  0.0  20.0   0.0  10.0
sph 4   0.0  0.0  0.0   1000.0
end
det   1
col   2  -1
out  -2
all   3
vac   4  -3
end
 1  2  3  4  5
 1  1  1  0  0
 1  2  -1000  -1  0
 5  5  1  0  2
101$$  25r1  t
0
```

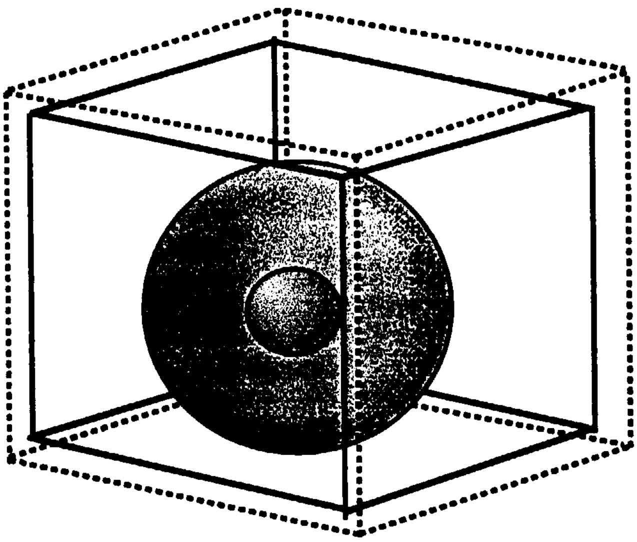
Fig. A-17 Geometry model description data for a sample geometry configuration with an array structure composed of single universe (see also Fig. A-16 (c)).

```
array test model (divide regions)
0   0   1  10
rcc 1   0.0  0.0  0.0   0.0  0.0 10.0   1.0
rpp 2  -2.0  2.0   -2.0  2.0   0.0 10.0
rpp 3   0.0  20.0  0.0  20.0   0.0  10.0
sph 4   0.0  0.0  0.0   1000.0
end
d01   1
c01   2  -1
o01  -2
d02   1
c02   2  -1
o02  -2
d03   1
c03   2  -1
o03  -2
d04   1
c04   2  -1
o04  -2
d05   1
c05   2  -1
o05  -2
d06   1
c06   2  -1
o06  -2
d07   1
c07   2  -1
o07  -2
d08   1
c08   2  -1
o08  -2
d09   1
c09   2  -1
o09  -2
d10   1
c10   2  -1
o10  -2
d11   1
c11   2  -1
o11  -2
d12   1
c12   2  -1
o12  -2
d13   1
c13   2  -1
o13  -2
d14   1
c14   2  -1
o14  -2d15    1
c15   2  -1
o15  -2
```

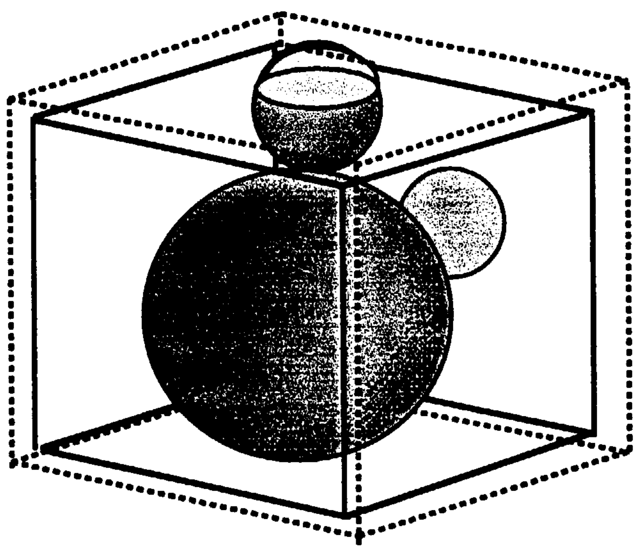
Fig. A-18 Geometry model description data for a sample geometry configuration with an array structure composed of different universes (see also Fig. A-16 (d)).

```
d16   1
c16   2  -1
o16  -2
d17   1
c17   2  -1
o17  -2
d18   1
c18   2  -1
o18  -2
d19   1
c19   2  -1
o19  -2
d20   1
c20   2  -1
o20  -2
d21   1
c21   2  -1
o21  -2
d22   1
c22   2  -1
o22  -2
d23   1
c23   2  -1
o23  -2
d24   1
c24   2  -1
o24  -2
d25   1
c25   2  -1
o25  -2
arr   3
vac   4  -3
end
  1  2  0  3  4  0  5  6  0  7  8  0  9 10  0
 11 12  0 13 14  0 15 16  0 17 18  0 19 20  0
 21 22  0 23 24  0 25 26  0 27 28  0 29 30  0
 31 32  0 33 34  0 35 36  0 37 38  0 39 40  0
 41 42  0 43 44  0 45 46  0 47 48  0 49 50  0
  0  0
 3*1  3*2  3*3  3*4  3*5   3*6  3*7  3*8  3*9  3*10
 3*11 3*12 3*13 3*14 3*15  3*16 3*17 3*18 3*19 3*20
 3*21 3*22 3*23 3*24 3*25   0   0
  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000
  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000
  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000
  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2 -1000  1  2
       -1000  1  2 -1000  1  2 -1000
 -1   0
 5  5  1  0  2
101$$  23i1 25  t
25*0
```

Fig. A-18 Geometry model description data for a sample geometry configuration with an array structure composed of different universes (see also Fig. A-16 (d)), (continued).



(a) simple universe



(b) combinatorial universe

Fig. A-19 Illustrations of a simple and a combinatorial universe.

Appendix B

Sample Problem for NMTC/JAERI97

Table B-1 Tally and its attribute implemented in NMTC/JAERI97.

Tally	Geometry type	Particle or data type	File unit and extension	Unit
Track length tally	Region	neutron, proton	32, regn	[/cm^2/Δ/source]
Surface crossing current spectrum tally	Surface on Z	neutron, proton, pion(+,0,-)	36, spct	[/cm^2/Δ/source]
Surface crossing flux tally	Surface on Z	neutron, proton, pion(+,0,-)	37, flux	[/cm^2/Δ/source]
Surface crossing current tally	Surface on Z	neutron, proton, pion(+,0,-)	38, curr	[/cm^2/Δ/source]
Nuclide yield tally	Region	Nuclide	40, yild	[/source]
Heat deposition tally	Region	Deuteron, triton , He-3 and α− particles emitted from fission fragments	51, ht.fis	[MeV/cm^3/source]
		Fission fragments	61, ht.frc	[MeV/cm^3/source]
		Deuteron, triton , He-3 and α− particles emitted from residual nucleus except fission fragment	52, ht.nuc	[MeV/cm^3/source]
		Excitation energy of residual nuclei	62, ht.nrc	[MeV/cm^3/source]
		Proton, pions and muons below cut-off energy	53, ht.cut	[MeV/cm^3/source]
		Leakage particles and cut-off neutron	54, ht.lkg	[MeV/source]
		Slowing down of Proton, pions and muons	55, ht.slw	[MeV/cm^3/source]
		Total and its components	56, ht.tot	[MeV/cm^3/source]

Note: Δ means the units of 'group', 'MeV', or 'lethargy', and it depends on the unit option selected by user .

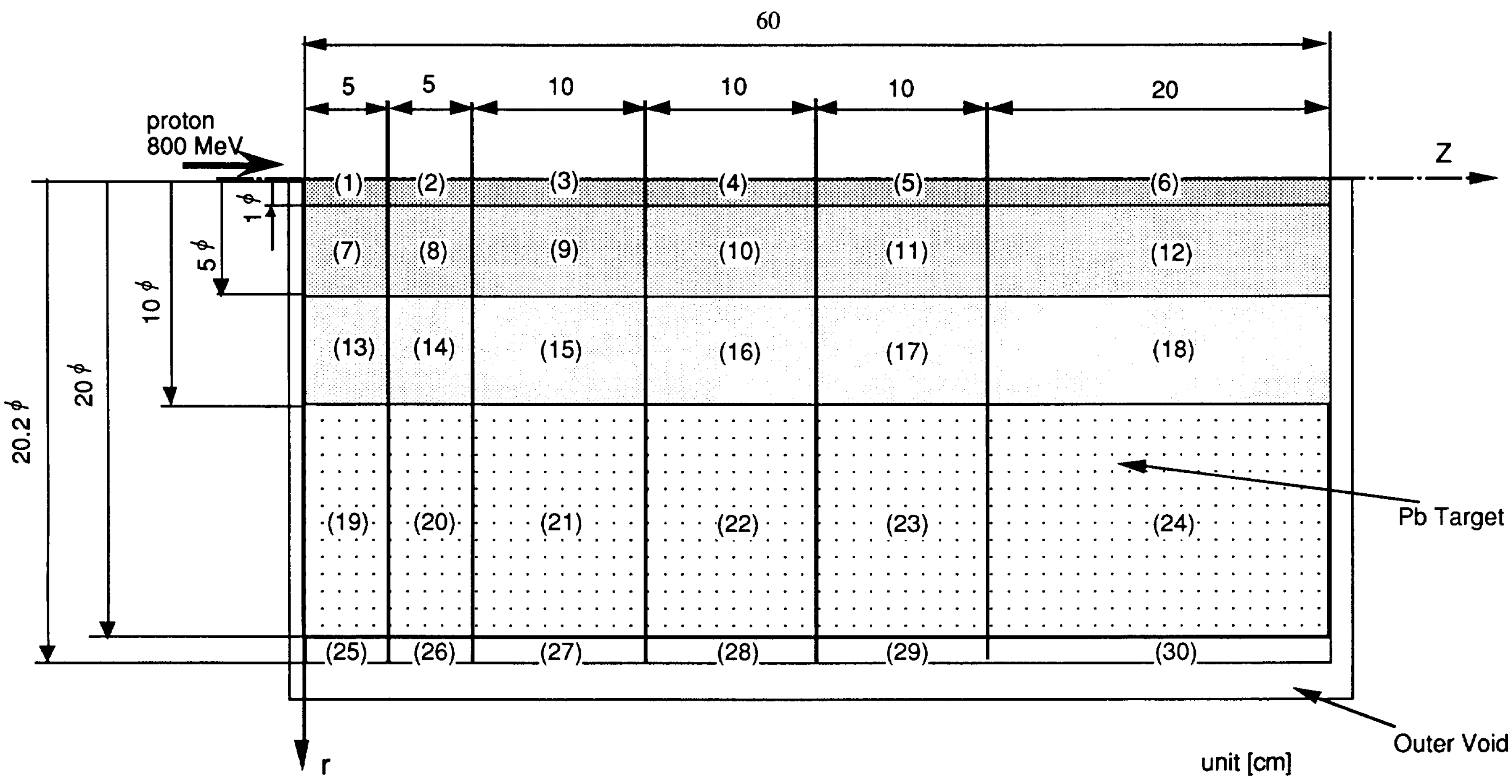


Fig. B-1 Illustration of the cylindrical lead target for the sample problem. The number in parentheses indicates the region number assigned in the input card.

```
#
#       @(#)Makefile   97/04/28
#
#       Makefile for test program of NMTC/JAERI-96CG/K
#       designed to work on HP workstations.
#
SRC = \
abran.f    absf.f     acnfsm.f   advijk.f   aiangl.f   aignt.f    \
ainter.f   aiout.f    aiouta.f   aitota.f   ajtest.f   alarge.f   \
alp19.f    alp28.f    alpha.f    amasse.f   amfp.f     analy3.f   \
analyz.f   angid.f    anglen.f   anglil.f   anrmrn.f   azio.f     \
azirn.f    bb.f       begin.f    bert.f     bessel.f   bg6b.f     \
bg6c.f     bg6ca.f    big7.f     binter.f   blkdat.f   block2.f   \
bovera.f   branch.f   calcu.f    cascad.f   cbrt.f     ccpes.f    \
celimp.f   chnumb.f   cii.f      ciic.f     ciicug.f              \
cij.f      cijc.f     cijcug.f              clock.f    cma.f      \
cmb.f      cmc.f      cole4.f    coll.f     collm.f    crdet.f    \
crjab.f    cubert.f   datahi.f   datalo.f   dbpnt.f    dcintp.f   \
dcpr.f     ddd.f      decay.f    delta.f    denl.f     dfmax.f    \
dis.f      dklos.f    dost.f     dres.f     dsda.f     dxde.f     \
ecol.f     ecpl.f     ecrd.f     edit.f     elas.f                \
           emte.f     en.f       endcde.f   endex.f    energy.f   \
engbin.f   erup.f     esneut.f   esprot.f              exprnf.f   \
fact.f     fact2.f    fidcom.f   find.f     finlii.f   finlij.f   \
fisbar.f   fischg.f   fispr.f    fltin.f    fltrn.f    frgen.f    \
fx.f       gamma.f    gaurn.f    gene.f     geo.f      getflt.f   \
getrig.f              gomprp.f   gomsor.f   gthsig.f   gtiso.f    \
gtiso2.f   heatpr.f   heattl.f   hilonx.f   hxs.f      iahn.f     \
iann.f     ianp.f     idk.f      iehn.f     ieidxn.f   ieidxp.f   \
ienn.f     ienp.f     ifrist.f   ioinit.f   isbert.f   isignk.f   \
isob.f     isom.f                kinels.f   look.f     m3.f       \
main.f     marslib.f             movlev.f   mud.f      nasanx.f   \
nasapx.f   nmtin.f    nmtin2.f   nregno.f   nsgels.f   nxttl.f    \
onepin.f   output.f   ovly11.f   ovly12.f   ovly21.f   ovly22.f   \
plclc.f    plcli.f    pangle.f   partin.f   pcol.f     pfmax.f    \
phase.f    pih.f      pinlpi.f   pinst.f    pnem2.f    poe.f      \
poll.f     psel.f     psgels.f   pstor.f    ptotal.f   punp.f     \
qalpha.f   qaze.f     qbnega.f   qdk.f      qdres.f    qecapt.f   \
qene.f     qfermi.f   qhe.f      qheavy.f   qklbch.f   qlp19.f    \
qlp28.f    qlpha.f    qneutr.f   qngid.f    qoll.f     qollm.f    \
qoul7.f    qoul8.f    qoul9.f    qou21.f    qprton.f   qq.f       \
qqhev2.f   qqhevy.f   qramda.f   qrdbfr.f   qrdet.f    qsddcs.f   \
qsgm.f     qsolag.f   qstor.f    rainge.f   rams.f     randin.f   \
randmc.f   rang.f     range.f    read22.f   readnm.f   recoil.f   \
refra.f    regnpr.f   regntl.f   resto.f    rlar.f     rndex.f    \
roul0.f    roul1.f    roul2.f    roul3.f    roul4.f    roul5.f    \
roul6.f    roul7.f    roul8.f    roul9.f    rou20.f    rou21.f    \
rou22.f    rout1.f    rout2.f    rout3.f    rout4.f    rout5.f    \
rout6.f    rout6a.f   rout7.f    rout7a.f   rout8.f    saveis.f   \
selcst.f   selj1.f    selpt.f    separn.f   separp.f   sgm.f      \
sig.f      signex.f   signk.f    simp.f     snn.f      solran.f   \
sors.f     spac32.f   spcn.f     spisom.f   sprd.f     ss.f       \
stat.f     store.f    stph.f     stpl.f     stpr.f     subfsm.f   \
sublib.f   submas.f   surfpr.f   surftl.f   syscon.f   tally.f    \
term2.f    term3.f    terpl.f    timex.f    tuyysh.f   tyield.f   \
undis.f    unirn.f    update.f   updeca.f   user.f     uuu.f      \
uuu2.f     wrntp3.f   wssto.f    wwsst.f    xcoll.f    xsec.f     \
xyi.f      yildpr.f   zero.f     zfoi.f
```

Fig. B-2 Example of a makefile shell script file for compiling source routines and linking object modules.

```
#
### for original NMTC, unmodified sobroutines were stored in ./old-f/
#
##### set executable file name #####
## 96cg/k version
EXE = ../nmtc96cg_k
##### set compile options #####
#FFLAGS = +U77 +T -K -O
#LFLAGS = +U77 -K
FFLAGS =
CFLAGS = -w -O

FC = f77
CC = cc

##### make executables #####
$(EXE): $(SRC:.f=.o)
	$(FC) -o $(EXE) $(LFLAGS) $(SRC:.f=.o)

##### make objects #####
.f.o:
	$(FC) -c $(FFLAGS) $<
.c.o:
	$(CC) -c $(CFLAGS) $<

##### clean-up #####
clean:
	rm -f core $(EXE:=.trace) *~ "#"*
objclean: clean
	rm -f $(SRC:.f=.o)
distclean: objclean
	rm -f $(EXE)
```

Fig. B-2 Example of a makefile shell script file for compiling source routines and linking object modules (continued).

```
#/bin/csh
#
#
#  shell script for nmtc/jaeri-96cg/k on SUN 4/20.
#
rm fort*
#
ln -s source.dat      fort.12
ln -s nmtc.out/ener   fort.31
ln -s nmtc.out/regn   fort.32
ln -s nmtc.out/spect  fort.36
ln -s nmtc.out/flux   fort.37
ln -s nmtc.out/curr   fort.38
ln -s nmtc.out/yield  fort.40
ln -s nmtc.out/dch    fort.41
ln -s nmtc.out/leak   fort.71
#
ln -s ../../SSL/nmtclb25.dat fort.21
ln -s ../../SSL/leveld.dat   fort.30
#
ln -s nmtc.out/ft50.out fort.50
ln -s nmtc.out/ft51.out fort.51
ln -s nmtc.out/ft52.out fort.52
ln -s nmtc.out/ft53.out fort.53
ln -s nmtc.out/ft54.out fort.54
ln -s nmtc.out/ft55.out fort.55
ln -s nmtc.out/ft56.out fort.56
ln -s nmtc.out/ft61.out fort.61
ln -s nmtc.out/ft62.out fort.62
#
 nmtc96cg_k < nmtin > out.nmtc
#
rm fort*
rm tmp.*
```

Fig. B-3 Example of a shell script file for execution.

```
CARD1:    spallation integral experiment analysis by nmtc/jaeri-cg96
CARD2:    #3: Pb-208, cylinder, d=20cm; importance
CARD3:    0.  0
CARD4:    800.        1.        20.        1       5000       10        0
CARD5:       1        23        21        11         0        22
CARD6:      0.        0.         1         0         0         0
CARD7:       1    1    2    3
CARD8A:            0.         1
CARD8B:            82.    208.   3.2959E-2
CARD9:    cylindrical target
CARD10:    0  0  1  0
CARD11:   rcc  1  0.0  0.0  0.0  0.0  0.0  5.0  0.5
          rcc  2  0.0  0.0  5.0  0.0  0.0  5.0  0.5
          rcc  3  0.0  0.0  10.0  0.0  0.0  10.0  0.5
          rcc  4  0.0  0.0  20.0  0.0  0.0  10.0  0.5
          rcc  5  0.0  0.0  30.0  0.0  0.0  10.0  0.5
          rcc  6  0.0  0.0  40.0  0.0  0.0  20.0  0.5
          rcc  7  0.0  0.0  0.0  0.0  0.0  5.0  2.5
          rcc  8  0.0  0.0  5.0  0.0  0.0  5.0  2.5
          rcc  9  0.0  0.0  10.0  0.0  0.0  10.0  2.5
          rcc  10  0.0  0.0  20.0  0.0  0.0  10.0  2.5
          rcc  11  0.0  0.0  30.0  0.0  0.0  10.0  2.5
          rcc  12  0.0  0.0  40.0  0.0  0.0  20.0  2.5
          rcc  13  0.0  0.0  0.0  0.0  0.0  5.0  5.0
          rcc  14  0.0  0.0  5.0  0.0  0.0  5.0  5.0
          rcc  15  0.0  0.0  10.0  0.0  0.0  10.0  5.0
          rcc  16  0.0  0.0  20.0  0.0  0.0  10.0  5.0
          rcc  17  0.0  0.0  30.0  0.0  0.0  10.0  5.0
          rcc  18  0.0  0.0  40.0  0.0  0.0  20.0  5.0
          rcc  19  0.0  0.0  0.0  0.0  0.0  5.0  10.0
          rcc  20  0.0  0.0  5.0  0.0  0.0  5.0  10.0
          rcc  21  0.0  0.0  10.0  0.0  0.0  10.0  10.0
          rcc  22  0.0  0.0  20.0  0.0  0.0  10.0  10.0
          rcc  23  0.0  0.0  30.0  0.0  0.0  10.0  10.0
          rcc  24  0.0  0.0  40.0  0.0  0.0  20.0  10.0
          rcc  25  0.0  0.0  0.0  0.0  0.0  5.0  10.1
          rcc  26  0.0  0.0  5.0  0.0  0.0  5.0  10.1
          rcc  27  0.0  0.0  10.0  0.0  0.0  10.0  10.1
          rcc  28  0.0  0.0  20.0  0.0  0.0  10.0  10.1
          rcc  29  0.0  0.0  30.0  0.0  0.0  10.0  10.1
          rcc  30  0.0  0.0  40.0  0.0  0.0  20.0  10.1
          rcc  31  0.0  0.0  -1.0  0.0  0.0  62.0  11.0
          end
CARD12:   t01    +1
          t02    +2
          t03    +3
          t04    +4
          t05    +5
          t06    +6
          t11    +7   -1
          t12    +8   -2
          t13    +9   -3
          t14    +10   -4
          t15    +11   -5
          t16    +12   -6
          t21    +13   -7
          t22    +14   -8
          t23    +15   -9
          t24    +16   -10
          t25    +17   -11
          t26    +18   -12
          t31    +19   -13
          t32    +20   -14
```

Fig. B-4 Input data for sample problem.

```
CARD12:  t33     +21  -15
         t34     +22  -16
         t35     +23  -17
         t36     +24  -18
         101     +25  -19
         102     +26  -20
         103     +27  -21
         104     +28  -22
         105     +29  -23
         106     +30  -24
         vid     +31  -25  -26  -27  -28  -29  -30
         out     -31
         end
CARD13:    1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17
           18  19  20  21  22  23  24  25  26  27  28  29  30  31  32
CARD14:    32*0
CARD15:    24*1   7*1000  0
CARD16:    0
-------
CARDS from 17 to 19 are omitted because array is not used.
-------
CARD20A:  importance
CARD20B:   1.0  2.0  4.0  8.0 16.0 32.0  1.0  2.0  4.0  8.0 16.0 32.0  1.0  2.0
           4.0  8.0 16.0 32.0  1.0  2.0  4.0  8.0 16.0 32.0  1.0  2.0  4.0  8.0
          16.0 32.0  1.0  0.0
CARD21:   source     1
CARD22A:        0.0     -0.10     -0.10     800.00        0.        0.        1.
CARD24:   tally     track
CARD24:   tally     surface
CARD24:   tally     yield
CARD24:   tally     heating
CARD25A:  energy    54
CARD25B:  energy      0.0      1.11      1.35      1.65      2.02      2.46
          energy      3.01     3.68      4.49      5.49      6.70      8.19
          energy     10.00    12.20     13.50     14.90     17.50     20.00
          energy     22.50    25.00     27.50     30.00     35.00     40.00
          energy     45.00    50.00     55.00     60.00     65.00     70.00
          energy     80.00    90.00    100.00    110.00    120.00    140.00
          energy    160.00   180.00    200.00    225.00    250.00    275.00
          energy    300.00   325.00    350.00    375.00    400.00    450.00
          energy    500.00   550.00    600.00    650.00    700.00    750.00
          energy    800.00
CARD26:   volume    3.9270      3.9270      7.8540      7.8540      7.8540
          volume    15.7080     94.2478     94.2478     188.4956    188.4956
          volume    188.4956    376.9911    294.5243    294.5243    589.0486
          volume    589.0486    589.0486    1178.0972   1178.0972   1178.0972
          volume    2356.1945   2356.1945   2356.1945   4712.3890   15.7472
          volume    15.7472     31.4945     31.4945     31.4945     62.9889
          volume    1.0         1.0
CARD27A:  r-surf    6
CARD27B:  r-surf    0.0  0.5  2.5  5.0  10.0  11.0
CARD28A:  z-surf    7
CARD28B:  z-surf    0.0  5.0  10.0  20.0  30.0  40.0  60.0
CARD30A:  y-region  24
CARD30B:  y-region  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
          y-region  23 24
CARD31A:  h-region  -24
CARD31C:  h-region  1  24
CARD32A:  t-region  0
CARD33:   sp-unit   1
CARD34:   pt-surf   5
```

Fig. B-4 Input data for sample problem (continued).

```
NMTC/JAERI : 96CG version (for HPUX mode)
 ---------------------------------------
   version  : 1997/04/16 (updated)
   job data : 1997/ 5/16
       time : 10H 14M 25S

 job title (1) .... spallation integral experiment analysis by nmtc/jaeri-cg96
           (2) .... #1: Pb-208, cylinder, d=20cm; no importance (weight)

 initial random number =                0.
 the number of skipped first random number sequence =          0

 emax    = 8.0000E+02 : energy of incident particle (MeV)
 emin(1)= 1.0000E+00 : cut-off energy of proton (MeV)
 emin(2)= 2.0000E+01 : cut-off energy of neutron (MeV)
 mxmat   =          1 : number of material regions
 maxcas  =       5000 : number of particles per one batch
 maxbch  =         10 : number of batches
 nlcol   =          0 : (no effect)

 nquit   =          1 : flag of repeated calculation (default=1)
 neutp   =         23 : (fixed to 23)
 nbertp  =         21 : (fixed to 21)
 npowr2  =         11 : (fixed to 11)
 npidk   =          0 : option of pi-meson (-)
                        <= 0, pi(-)
                        >  0, decay
 nhstp   =         22 : (fixed to 22)

 andt    =  .0000E+00 : option of angular distribution of isobar
                        0.0, isotropic-50% and forward-50%
                        1.0, isotropic-100%
                        2.0, forward-100%
 ctofe   =  .0000E+00 : (fiexed to 0.0)
 nbogus  =          1 : option of evapolation calculation
                        < 0, no calculation
                        > 0, correction of recoil energy before evapolation
                        = 0, no correction of recoil energy
 nspred  =          0 : option of proton beam expansion by Coulomb power
                        > 0, effect
                        <=0, no effect
 nwsprd  =          0 : option of trajectory of incident proton
                        > 0, recording
                        <=0, no record
 nseudo  =          0 : option of pseudo random number
                        > 0, recording
                        <=0, no record

 ==========  using models and parameters  ===================================================
 Total, elastic and non-elastic cross sections evaluated by pearlstein is used in transport calculation.
 Nuclear reaction is calculated by cascade-evaporation model.
 Bertini model is used for intranuclear cascade calculation.
 Ignatyuk formulation is used as level density parameter.
 ============================================================================================


 hsigmx     6.73000E-25    4.80000E-25    2.00300E-25     .00000E+00     6.69000E-26
 this is medium  1

 denh( 1) = .000000E+00  nel( 1) =  1
 zz( 1, 1) =82.0  a( 1, 1) =208.0  den( 1, 1) = 3.29590E-02

 *geometric* cross sections for nuclides 1- 1 in medium  1 in reciprocal centimeters
   8.1130E-02

     maximum hydrogen cross sections for particle types 1 through 5 in medium  1 in reciprocal centimeters
             .0000E+00      .0000E+00      .0000E+00      .0000E+00      .0000E+00

     transport cross sections (the sum of *geometric* xsec + max.hydrogen xsec + max.decay xsec) for particle
      types 1 through 7 in medium  1 in reciprogal centimeters
             8.1130E-02    8.1130E-02    1.0842E-01     .0000E+00    1.0842E-01    3.4538E-04    3.4538E-04
```

Fig. B-5 Output file on the locgical unit 6.

```
(eliminated for combination geometry data)


the cell importance function by user
-----------------------------------
decade          1            2            3            4            5            6            7            8
           9           10
    0  1.000E+00   2.000E+00   4.000E+00   8.000E+00   1.600E+01   3.200E+01   1.000E+00   2.000E+00
         4.000E+00   8.000E+00
   10  1.600E+01   3.200E+01   1.000E+00   2.000E+00   4.000E+00   8.000E+00   1.600E+01   3.200E+01
         1.000E+00   2.000E+00
   20  4.000E+00   8.000E+00   1.600E+01   3.200E+01   1.000E+00   2.000E+00   4.000E+00   8.000E+00
         1.600E+01   3.200E+01
   30  1.000E+00    .000E+00


mono-energetic axial source of radius (r) =  .00000E+00 at axis range (z) =-1.00000E-01 to -1.00000E-01  [cm]
energy = 8.00000E+02   tip = 0.  direc=     1.000


Input data description for NMTC tally module
using tally (or detector) options
---------------------------------
 italxx(1)= 1 : track length tally (0/1=no/yes)
       (2)= 1 : surface crossing spectrum tally (0/1=no/yes)
       (3)= 1 : surface crossing flux tally (0/1=no/yes)
       (4)= 1 : surface crossing current tally (0/1=no/yes)
       (5)= 1 : regionwise nuclear yields (or production rate) (0/1=no/yes)
       (6)= 1 : regionwise nuclear heating (0/1=no/yes)

energy group boundaries [MeV] ....... group =    54
         1   .00000E+00     12  8.19000E+00     23  3.50000E+01     34  1.10000E+02     45  3.50000E+02
         2  1.11000E+00     13  1.00000E+01     24  4.00000E+01     35  1.20000E+02     46  3.75000E+02
         3  1.35000E+00     14  1.22000E+01     25  4.50000E+01     36  1.40000E+02     47  4.00000E+02
         4  1.65000E+00     15  1.35000E+01     26  5.00000E+01     37  1.60000E+02     48  4.50000E+02
         5  2.02000E+00     16  1.49000E+01     27  5.50000E+01     38  1.80000E+02     49  5.00000E+02
         6  2.46000E+00     17  1.75000E+01     28  6.00000E+01     39  2.00000E+02     50  5.50000E+02
         7  3.01000E+00     18  2.00000E+01     29  6.50000E+01     40  2.25000E+02     51  6.00000E+02
         8  3.68000E+00     19  2.25000E+01     30  7.00000E+01     41  2.50000E+02     52  6.50000E+02
         9  4.49000E+00     20  2.50000E+01     31  8.00000E+01     42  2.75000E+02     53  7.00000E+02
        10  5.49000E+00     21  2.75000E+01     32  9.00000E+01     43  3.00000E+02     54  7.50000E+02
        11  6.70000E+00     22  3.00000E+01     33  1.00000E+02     44  3.25000E+02     55  8.00000E+02

region volumes [cm3] ....... region =   32
         1  3.927000E+00     8  9.424780E+01    15  5.890486E+02    22  2.356195E+03    29  3.149450E+01
         2  3.927000E+00     9  1.884956E+02    16  5.890486E+02    23  2.356195E+03    30  6.298890E+01
         3  7.854000E+00    10  1.884956E+02    17  5.890486E+02    24  4.712389E+03    31  1.000000E+00
         4  7.854000E+00    11  1.884956E+02    18  1.178097E+03    25  1.574720E+01    32  1.000000E+00
         5  7.854000E+00    12  3.769911E+02    19  1.178097E+03    26  1.574720E+01
         6  1.570800E+01    13  2.945243E+02    20  1.178097E+03    27  3.149450E+01
         7  9.424780E+01    14  2.945243E+02    21  2.356195E+03    28  3.149450E+01

radial boundaries of surface tally [cm] ....... boundary =     6
         1          .000     3        2.500     5       10.000
         2          .500     4        5.000     6       11.000

radial boundaries of surface tally [cm] ....... boundary =     7
         1          .000     4       20.000     7       60.000
         2         5.000     5       30.000
         3        10.000     6       40.000

yield tally region numbers ....... region =    24
         1     2     3     4     5     6     7     8     9    10    11    12    13    14    15
        16    17    18    19    20    21    22    23    24

heating tally region numbers ....... region =    24
         1     2     3     4     5     6     7     8     9    10    11    12    13    14    15
        16    17    18    19    20    21    22    23    24

track length tally region numbers ....... region =    32    (all region)
```

Fig. B-5 Output file on the logical unit 6 (continued).

```
ksunit =  1 : output unit of spectrum (0/1/2=group/MeV/lethargy)

kpsurf =  5 : number of talling particles by surface tally (default=3)
              2 = neutron and proton
              3 = neutron, proton, pion
              5 = neutron, proton, pion(+,0,-)

location assiginment for tally in das-array
    ltaltr =      141 : starting address of track length tally
    ltalsp =     7053 : starting address of spectrum by surface tally
    ltalsf =    25953 : starting address of flux by surface tally
    ltalsc =    44853 : starting address of current by surface tally
    ltalyd =    45553 : starting address of nuclear yield tally
    ltalht =   146353 : starting address of nuclear heating tally

storage size for tally data ..... used      149713
                            ..... extra    1350287
--------------------------------------------------

no history tape (hstp) and high-energy particles output on tape-11, but low-energy neutrons output on tape-12.

source    energy          x           y           z           u           v           w       weight   tip
     1 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     2 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     3 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     4 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     5 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     6 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     7 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     8 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
     9 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    10 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    11 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    12 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    13 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    14 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    15 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    16 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    17 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    18 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    19 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    20 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    21 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    22 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    23 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    24 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
    25 8.000E+02   .0000E+00   .0000E+00 -1.0000E-01   .0000E+00   .0000E+00  1.0000E+00  1.0000E+00   0.
batch    1  cutoff-neutrons=  440613, cumulative cascades=     5000, random=230244868571869., calls=    227547412
            cutoff-n weight= 9.0941314E+04
cpu time= 23 m. 21.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ............................       1
        number of pseudo fissions ................................................       1

batch    2  cutoff-neutrons=  438263, cumulative cascades=    10000, random=149615541184637., calls=    454150768
            cutoff-n weight= 9.1222659E+04
cpu time= 46 m. 39.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ............................       1
        number of pseudo fissions ................................................       4

batch    3  cutoff-neutrons=  443438, cumulative cascades=    15000, random= 48971547836957., calls=    683776531
            cutoff-n weight= 9.0980517E+04
cpu time=  1 h. 10 m. 13.00 s.
batch    4  cutoff-neutrons=  438225, cumulative cascades=    20000, random=263668874219453., calls=    910643705
            cutoff-n weight= 9.0957675E+04
cpu time=  1 h. 33 m. 31.00 s.
--- warning message from ovly12 ---
        detected number of A < Z   nuclide in f.energy ............................       1
                    1   2
```

Fig. B-5 Output file on the logical unit 6 (continued).

```
batch   5  cutoff-neutrons=  439508, cumulative cascades=   25000, random=278671286112605., calls=   1136795027
           cutoff-n weight= 9.2285847E+04
cpu time=  1 h. 56 m. 47.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ...........................          1
        number of pseudo fissions ................................................          2

batch   6  cutoff-neutrons=  441919, cumulative cascades=   30000, random=241791224284925., calls=   1364372945
           cutoff-n weight= 9.1481063E+04
cpu time=  2 h. 20 m. 12.00 s.
--- warning message from ovly12 ---
        number of pseudo fissions ................................................          2

batch   7  cutoff-neutrons=  436972, cumulative cascades=   35000, random= 52435619442845., calls=   1590360163
           cutoff-n weight= 9.0836438E+04
cpu time=  2 h. 43 m. 25.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ...........................          2
        detected number of A < Z   nuclide in f.energy ...........................          1
                   1   2
        number of pseudo fissions ................................................          1

batch   8  cutoff-neutrons=  436796, cumulative cascades=   40000, random=107690466135613., calls=   1816133774
           cutoff-n weight= 9.0329946E+04
cpu time=  3 h.  6 m. 38.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ...........................          2
        detected number of A < Z   nuclide in f.energy ...........................          1
                   2   3
        number of pseudo fissions ................................................          4
        detected number of particle energy less than "emin" ..................    2    0    0    0    0    0    0

batch   9  cutoff-neutrons=  441598, cumulative cascades=   45000, random=  8533228003293., calls=   2043731975
           cutoff-n weight= 9.1429306E+04
cpu time=  3 h. 30 m.  3.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ...........................          3

batch  10  cutoff-neutrons=  439248, cumulative cascades=   50000, random=251387889902973., calls=   2270840941
           cutoff-n weight= 9.0979601E+04
cpu time=  3 h. 53 m. 24.00 s.
--- warning message from ovly12 ---
        detected number of A < 0.0 nuclide in f.energy ...........................          2

batch no. =        1         2         3         4         5         6         7         8         9        10
neutrons  =   440613    438263    443438    438225    439508    441919    436972    436796    441598    439248
prod. wgt =   18.188    18.245    18.196    18.192    18.457    18.296    18.167    18.066    18.286    18.196
average production weight per source =  18.22889    std.dev. =    .10310

pi (+)    =     1949      2041      1953      1875      1790      1873      1799      1895      1857      1797
prod. wgt =     .145      .154      .135      .138      .138      .134      .137      .136      .135      .126
average production weight per source =    .13773    std.dev. =    .00721

pi (zero) =     2018      2059      2011      1965      2046      1976      2213      1899      2114      2018
prod. wgt =     .132      .132      .135      .133      .141      .125      .146      .129      .137      .137
average production weight per source =    .13469    std.dev. =    .00599

pi (-)    =     2739      2580      2781      2612      2771      2649      2670      2612      2643      2695
prod. wgt =     .150      .135      .134      .143      .160      .145      .138      .132      .146      .151
average production weight per source =    .14336    std.dev. =    .00877

fissions  =     1080      1085      1080      1084      1069      1073      1106      1111      1109      1083
prod. wgt =     .067      .065      .067      .067      .068      .068      .068      .069      .072      .065
average production weight per source =    .06768    std.dev. =    .00211


  (numbers)                real               pseudo               real               pseudo               pseudo
  ---------       nonhydrogenous       nonhydrogenous           hydrogen             hydrogen                decay
                      collisions           collisions         collisions           collisions           collisions
  medium  1             644354.0             289286.0                 .0                   .0               7676.0
```

Fig. B-5 Output file on the logical unit 6 (continued).

(weight)	real nonhydrogenous collisions	pseudo nonhydrogenous collisions	real hydrogen collisions	pseudo hydrogen collisions	pseudo decay collisions
--------					
medium 1	1.169448E+05	5.281720E+04	.000000E+00	.000000E+00	2.353003E+03

status of cell importance sampling (splitting and roulette)

reg.	importance	outgoing weight	splitted weight	splitted number	survived weight	killed weight
1	1.0000E+00	8.5332E-01	4.2666E-01	2.0000	.0000E+00	.0000E+00
2	2.0000E+00	6.4829E-01	3.2414E-01	2.0000	8.7396E-03	3.6598E-03
3	4.0000E+00	3.6506E-01	1.8253E-01	2.0000	4.4995E-03	2.4196E-03
4	8.0000E+00	2.0796E-01	1.0398E-01	2.0000	1.7000E-03	8.7496E-04
5	1.6000E+01	1.1588E-03	5.7938E-04	2.0000	4.8000E-04	3.0500E-04
6	3.2000E+01	.0000E+00	.0000E+00	.0000	6.1250E-05	5.3750E-05
7	1.0000E+00	1.8491E-01	9.2455E-02	2.0000	.0000E+00	.0000E+00
8	2.0000E+00	1.9076E-01	9.5381E-02	2.0000	2.1735E-02	1.0947E-02
9	4.0000E+00	1.1296E-01	5.6479E-02	2.0000	1.3325E-02	7.7131E-03
10	8.0000E+00	5.6149E-02	2.8075E-02	2.0000	5.2738E-03	3.4846E-03
11	1.6000E+01	1.5282E-02	7.6412E-03	2.0000	2.1074E-03	1.4050E-03
12	3.2000E+01	.0000E+00	.0000E+00	.0000	1.0488E-03	1.1025E-03
13	1.0000E+00	7.4455E-02	3.7228E-02	2.0000	.0000E+00	.0000E+00
14	2.0000E+00	1.2446E-01	6.2231E-02	2.0000	1.6395E-02	8.4285E-03
15	4.0000E+00	1.0996E-01	5.4982E-02	2.0000	1.3937E-02	7.7436E-03
16	8.0000E+00	6.2534E-02	3.1267E-02	2.0000	7.7386E-03	5.1569E-03
17	1.6000E+01	2.3769E-02	1.1884E-02	2.0000	2.9798E-03	2.7437E-03
18	3.2000E+01	.0000E+00	.0000E+00	.0000	2.8512E-03	2.9162E-03
19	1.0000E+00	3.9338E-02	1.9669E-02	2.0000	.0000E+00	.0000E+00
20	2.0000E+00	9.7373E-02	4.8686E-02	2.0000	1.7874E-02	9.4271E-03
21	4.0000E+00	1.2956E-01	6.4781E-02	2.0000	1.5786E-02	9.0378E-03
22	8.0000E+00	9.0995E-02	4.5498E-02	2.0000	9.6140E-03	6.6994E-03
23	1.6000E+01	4.5898E-02	2.2949E-02	2.0000	4.9749E-03	4.1136E-03
24	3.2000E+01	.0000E+00	.0000E+00	.0000	9.1375E-03	8.3567E-03
25	1.0000E+00	3.6000E-04	1.8000E-04	2.0000	.0000E+00	.0000E+00
26	2.0000E+00	8.7000E-04	4.3500E-04	2.0000	1.0757E-01	5.4555E-02
27	4.0000E+00	1.6649E-03	8.3246E-04	2.0000	2.3872E-01	1.7693E-01
28	8.0000E+00	1.3500E-03	6.7500E-04	2.0000	1.6987E-01	1.4961E-01
29	1.6000E+01	9.2374E-04	4.6187E-04	2.0000	8.9721E-02	8.3185E-02
30	3.2000E+01	.0000E+00	.0000E+00	.0000	4.8188E-02	4.6275E-02
31	1.0000E+00	4.8039E-02	1.3317E-02	3.6073	.0000E+00	.0000E+00
32	.0000E+00	.0000E+00	.0000E+00	.0000	.0000E+00	.0000E+00

--- warning --- 5917 residual nuclei had negative excitation energy.

number of collisions written on history tape, vs. ncol

-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
1	10	0	1	10832	50000	916112	679124	39614	0	106574	2250497	0

next initial random number = 223416281636313.0

```
total number of cut-off neutrons =        4396580
total weight of cut-off neutrons =  9.1144437E+05
average weight per source        =       18.22889
cpu time=  3 h. 53 m. 26.00 s.

job termination date : 1997/ 5/16
                time : 14H  8M 18S
```

Fig. B-5 Output file on the logical unit 6 (continued).

```
regionwise flux by track length tally   [/cm**2/MeV/source]
------------------------------------

no.  1: region    1 ..... volume=  3.92700E+00 [cm**3]
reg. energy[MeV]          neutron                   proton
          .000            flux      r.err            flux     r.err
  1      1.110       .0000E+00   .0000       .0000E+00   .0000
  1      1.350       .0000E+00   .0000     2.2533E-04   .0037
  1      1.650       .0000E+00   .0000     2.3802E-04   .0037
  1      2.020       .0000E+00   .0000     2.5630E-04   .0037
  1      2.460       .0000E+00   .0000     2.7972E-04   .0037
  1      3.010       .0000E+00   .0000     3.0857E-04   .0037
  1      3.680       .0000E+00   .0000     3.4280E-04   .0037
  1      4.490       .0000E+00   .0000     3.7996E-04   .0037
  1      5.490       .0000E+00   .0000     4.1323E-04   .0039
  1      6.700       .0000E+00   .0000     4.3242E-04   .0042
  1      8.190       .0000E+00   .0000     4.2267E-04   .0048
  1     10.000       .0000E+00   .0000     3.9068E-04   .0057
  1     12.200       .0000E+00   .0000     3.5671E-04   .0068
  1     13.500       .0000E+00   .0000     3.3784E-04   .0077
  1     14.900       .0000E+00   .0000     3.2162E-04   .0083
  1     17.500       .0000E+00   .0000     2.9795E-04   .0092
  1     20.000       .0000E+00   .0000     2.7731E-04   .0103
  1     22.500     2.0212E-03   .0302     2.6540E-04   .0112
  1     25.000     1.6889E-03   .0318     2.5800E-04   .0119
  1     27.500     1.4501E-03   .0363     2.5521E-04   .0125
  1     30.000     1.1966E-03   .0390     2.5333E-04   .0131
  1     35.000     1.0183E-03   .0287     2.5034E-04   .0137
  1     40.000     8.8615E-04   .0316     2.4777E-04   .0146
  1     45.000     7.2830E-04   .0347     2.4062E-04   .0156
  1     50.000     6.5425E-04   .0381     2.3605E-04   .0164
  1     55.000     6.0680E-04   .0374     2.3165E-04   .0172
  1     60.000     6.0097E-04   .0397     2.2387E-04   .0182
  1     65.000     4.8305E-04   .0441     2.1791E-04   .0190
  1     70.000     4.4081E-04   .0460     2.1198E-04   .0199
  1     80.000     4.2377E-04   .0332     2.0372E-04   .0205
  1     90.000     3.8054E-04   .0356     1.9104E-04   .0221
  1    100.000     3.1784E-04   .0397     1.7880E-04   .0238
  1    110.000     2.8926E-04   .0431     1.7215E-04   .0250
  1    120.000     2.4496E-04   .0460     1.6444E-04   .0265
  1    140.000     2.2423E-04   .0353     1.5353E-04   .0266
  1    160.000     1.7700E-04   .0413     1.4171E-04   .0291
  1    180.000     1.7126E-04   .0435     1.3579E-04   .0312
  1    200.000     1.7572E-04   .0470     1.2602E-04   .0338
  1    225.000     1.6719E-04   .0494     1.1219E-04   .0353
  1    250.000     1.4833E-04   .0547     9.0306E-05   .0399
  1    275.000     8.9280E-05   .0671     6.9536E-05   .0462
  1    300.000     5.6177E-05   .0745     6.0159E-05   .0507
  1    325.000     4.4712E-05   .0819     5.2346E-05   .0561
  1    350.000     3.9732E-05   .0875     4.7718E-05   .0598
  1    375.000     3.8868E-05   .0961     3.9378E-05   .0685
  1    400.000     3.2605E-05   .1095     3.4427E-05   .0718
  1    450.000     1.8064E-05   .0964     2.4229E-05   .0681
  1    500.000     1.9273E-05   .0968     2.1297E-05   .0722
  1    550.000     1.3813E-05   .1039     2.1107E-05   .0693
  1    600.000     1.5219E-05   .1039     2.4014E-05   .0669
  1    650.000     1.5336E-05   .1038     2.9508E-05   .0631
  1    700.000     1.7911E-05   .0958     4.6245E-05   .0547
  1    750.000     2.5727E-05   .0947     6.3593E-03   .0022
  1    800.000     1.7616E-05   .1359     1.5965E-02   .0011
  1      total     9.7084E-02   .0079     1.1758E+00   .0010
```

Fig. B-6 Example of an output file of the track length tally.

no. 2: spectra at axial surface, z= 5.00 [cm]

in radial mesh between .00 and .50 [cm] ..... area= 7.853982E-01 [cm2]

energy [MeV]	proton		neutron		pion(+)		pion(0)		pion(-)	
1.11	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
1.35	.0000E+00	.0000	.0000E+00	.0000	1.0610E-04	1.0000	.0000E+00	.0000	.0000E+00	.0000
1.65	2.1221E-04	.6000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	8.4883E-05	1.0000
2.02	3.4412E-05	1.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
2.46	8.6812E-05	.7453	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
3.01	2.5465E-04	.3748	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
3.68	5.7011E-05	.7453	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
4.49	7.8595E-05	.5291	.0000E+00	.0000	3.1438E-05	.7071	.0000E+00	.0000	.0000E+00	.0000
5.49	2.1645E-04	.2941	.0000E+00	.0000	1.2732E-05	1.0000	.0000E+00	.0000	.0000E+00	.0000
6.70	3.0516E-04	.2313	.0000E+00	.0000	4.2091E-05	.7071	.0000E+00	.0000	.0000E+00	.0000
8.19	2.1363E-04	.2433	.0000E+00	.0000	8.5452E-06	1.0000	.0000E+00	.0000	.0000E+00	.0000
10.00	1.9697E-04	.2474	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	3.5172E-05	.6000
12.20	2.7201E-04	.1938	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
13.50	9.7942E-05	.3741	.0000E+00	.0000	4.8971E-05	.5291	.0000E+00	.0000	.0000E+00	.0000
14.90	1.0004E-04	.3748	.0000E+00	.0000	1.8189E-05	.7071	.0000E+00	.0000	9.0946E-06	1.0000
17.50	1.5181E-04	.2348	.0000E+00	.0000	1.9588E-05	.7071	.0000E+00	.0000	.0000E+00	.0000
20.00	7.1301E-05	.3350	.0000E+00	.0000	1.0186E-05	.7071	.0000E+00	.0000	5.0930E-06	1.0000
22.50	1.0186E-04	.3000	1.2580E-03	.0839	3.0558E-05	.4082	.0000E+00	.0000	2.0372E-05	.6124
25.00	1.5279E-04	.2403	9.8294E-04	.0953	3.0558E-05	.5270	.0000E+00	.0000	3.0558E-05	.4714
27.50	1.5788E-04	.2477	9.3710E-04	.0974	4.0744E-05	.4330	.0000E+00	.0000	1.0079E-05	1.0000
30.00	1.4260E-04	.2624	7.5885E-04	.1104	3.0558E-05	.4082	.0000E+00	.0000	1.5279E-05	.5773
35.00	1.3496E-04	.1914	5.5513E-04	.0912	1.7825E-05	.4738	.0000E+00	.0000	1.2732E-05	.5291
40.00	1.1459E-04	.2024	5.3476E-04	.0944	1.0186E-05	.5000	.0000E+00	.0000	1.0164E-05	.5000
45.00	1.2478E-04	.1925	3.6160E-04	.1135	1.0186E-05	.5000	.0000E+00	.0000	2.5465E-06	1.0000
50.00	1.4515E-04	.1831	4.0489E-04	.1090	2.2918E-05	.4006	.0000E+00	.0000	2.5465E-06	1.0000
55.00	1.4515E-04	.1848	4.4309E-04	.1037	1.5279E-05	.4714	.0000E+00	.0000	5.0930E-06	.7071
60.00	1.4006E-04	.1880	3.6669E-04	.1140	1.7810E-05	.3779	.0000E+00	.0000	2.5465E-06	1.0000
65.00	1.5024E-04	.1801	2.5465E-04	.1370	5.0930E-06	.7071	.0000E+00	.0000	5.0930E-06	.7071
70.00	1.4260E-04	.1855	3.1576E-04	.1249	2.5465E-06	1.0000	.0000E+00	.0000	7.6394E-06	.7453
80.00	1.0184E-04	.1551	2.8139E-04	.0932	6.3662E-06	.5291	.0000E+00	.0000	7.6394E-06	.5270
90.00	1.2478E-04	.1421	2.5847E-04	.0971	1.0168E-05	.4332	.0000E+00	.0000	2.5465E-06	1.0000
100.00	1.4642E-04	.1298	2.0372E-04	.1089	6.3568E-06	.5294	.0000E+00	.0000	6.3449E-06	.5998
110.00	1.5406E-04	.1272	2.1517E-04	.1072	6.3662E-06	.6000	.0000E+00	.0000	7.6394E-06	.5773
120.00	1.4006E-04	.1329	1.7061E-04	.1202	7.6218E-06	.5268	.0000E+00	.0000	.0000E+00	.0000
140.00	1.4197E-04	.0941	1.8335E-04	.0828	1.0186E-05	.3423	.0000E+00	.0000	1.2732E-06	1.0000
160.00	1.1905E-04	.1029	1.4833E-04	.0918	5.0930E-06	.5000	.0000E+00	.0000	.0000E+00	.0000
180.00	1.2287E-04	.1010	1.4196E-04	.0943	7.6322E-06	.4082	.0000E+00	.0000	2.5465E-06	.7071
200.00	9.9949E-05	.1126	2.2027E-04	.0758	5.0930E-06	.5000	.0000E+00	.0000	.0000E+00	.0000
225.00	9.6766E-05	.1020	2.0066E-04	.0711	9.1673E-06	.3333	.0000E+00	.0000	.0000E+00	.0000
250.00	6.9264E-05	.1212	1.8997E-04	.0728	4.0744E-06	.5000	.0000E+00	.0000	3.0558E-06	.5773
275.00	4.1762E-05	.1561	8.6580E-05	.1077	6.1115E-06	.4082	.0000E+00	.0000	2.0327E-06	.7071
300.00	5.9078E-05	.1312	6.3153E-05	.1269	8.1412E-06	.3535	.0000E+00	.0000	.0000E+00	.0000
325.00	4.8892E-05	.1435	3.6669E-05	.1666	4.0744E-06	.5000	.0000E+00	.0000	.0000E+00	.0000
350.00	4.7874E-05	.1458	3.6160E-05	.1672	3.0558E-06	.5773	.0000E+00	.0000	.0000E+00	.0000
375.00	3.4632E-05	.1714	2.9539E-05	.1856	3.0558E-06	.5773	.0000E+00	.0000	.0000E+00	.0000
400.00	2.6483E-05	.1961	3.3614E-05	.1740	1.0186E-06	1.0000	.0000E+00	.0000	.0000E+00	.0000
450.00	2.0372E-05	.1581	2.0372E-05	.1581	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
500.00	1.6297E-05	.1767	2.1900E-05	.1515	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
550.00	2.2409E-05	.1507	1.1714E-05	.2085	.0000E+00	.0000	.0000E+00	.0000	5.0930E-07	1.0000
600.00	3.0558E-05	.1290	1.3751E-05	.1924	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
650.00	3.7179E-05	.1170	2.0372E-05	.1581	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
700.00	6.4935E-05	.0884	2.5974E-05	.1400	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
750.00	1.9429E-02	.0025	3.3359E-05	.1232	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
800.00	.0000E+00	.0000	1.2478E-05	.2009	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000

Fig. B-7 Example of an output file of the surface crossing current spectrum tally.

no. 2: spectra at axial surface, z= 5.00 [cm]

in radial mesh between .00 and .50 [cm] ..... area= 7.853982E-01 [cm2]

energy [MeV]	proton		neutron		pion(+)		pion(0)		pion(-)	
1.11	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
1.35	.0000E+00	.0000	.0000E+00	.0000	1.3724E-04	1.0000	.0000E+00	.0000	.0000E+00	.0000
1.65	3.9534E-04	.6399	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	8.8761E-05	1.0000
2.02	4.8539E-05	1.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
2.46	1.1703E-04	.7477	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
3.01	6.4242E-04	.4141	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
3.68	7.0001E-05	.7487	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
4.49	1.4683E-04	.5091	.0000E+00	.0000	3.5031E-05	.7106	.0000E+00	.0000	.0000E+00	.0000
5.49	3.7035E-04	.3102	.0000E+00	.0000	1.4107E-05	1.0000	.0000E+00	.0000	.0000E+00	.0000
6.70	4.3078E-04	.2429	.0000E+00	.0000	4.3458E-05	.7074	.0000E+00	.0000	.0000E+00	.0000
8.19	4.1418E-04	.2828	.0000E+00	.0000	2.0683E-05	1.0000	.0000E+00	.0000	.0000E+00	.0000
10.00	3.3141E-04	.2633	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	5.9005E-05	.6401
12.20	3.9437E-04	.1963	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
13.50	1.5265E-04	.4320	.0000E+00	.0000	7.2641E-05	.5329	.0000E+00	.0000	.0000E+00	.0000
14.90	2.0859E-04	.3786	.0000E+00	.0000	2.8293E-05	.7300	.0000E+00	.0000	2.0345E-05	1.0000
17.50	3.6721E-04	.3075	.0000E+00	.0000	2.2274E-05	.7119	.0000E+00	.0000	.0000E+00	.0000
20.00	1.1693E-04	.3411	.0000E+00	.0000	2.9260E-05	.7072	.0000E+00	.0000	6.4053E-06	1.0000
22.50	2.4604E-04	.3719	1.9973E-03	.1064	3.2464E-05	.4085	.0000E+00	.0000	3.8090E-05	.6028
25.00	2.1975E-04	.2517	1.5811E-03	.1169	5.5411E-05	.5874	.0000E+00	.0000	8.3522E-05	.6022
27.50	2.4464E-04	.2805	1.4222E-03	.1080	7.4067E-05	.5141	.0000E+00	.0000	1.0437E-05	1.0000
30.00	2.3892E-04	.3255	1.1796E-03	.1213	5.1511E-05	.4538	.0000E+00	.0000	1.9471E-05	.5789
35.00	2.1709E-04	.2054	1.4712E-03	.2887	2.2576E-05	.4588	.0000E+00	.0000	2.8010E-05	.6198
40.00	2.4477E-04	.2407	7.9935E-04	.1062	1.2673E-05	.5046	.0000E+00	.0000	1.3525E-05	.5110
45.00	2.2407E-04	.2373	5.4476E-04	.1334	1.1412E-05	.5008	.0000E+00	.0000	3.8919E-06	1.0000
50.00	2.7615E-04	.2550	6.5416E-04	.1342	5.7491E-05	.5331	.0000E+00	.0000	4.5535E-06	1.0000
55.00	2.2833E-04	.2056	6.1890E-04	.1158	2.1779E-05	.4618	.0000E+00	.0000	7.0411E-06	.7073
60.00	2.5638E-04	.2157	5.0542E-04	.1196	3.2137E-05	.4065	.0000E+00	.0000	1.6971E-05	1.0000
65.00	2.1709E-04	.1988	4.1186E-04	.1759	8.1008E-06	.7346	.0000E+00	.0000	5.2508E-06	.7073
70.00	2.0168E-04	.1931	4.6645E-04	.1387	2.5560E-06	1.0000	.0000E+00	.0000	9.3793E-06	.7512
80.00	1.4224E-04	.1613	3.9878E-04	.1015	2.3983E-05	.7434	.0000E+00	.0000	1.4867E-05	.6681
90.00	1.9180E-04	.1636	3.6381E-04	.1128	1.1100E-05	.4396	.0000E+00	.0000	5.1518E-06	1.0000
100.00	2.4389E-04	.2664	2.9699E-04	.1346	7.7764E-06	.5161	.0000E+00	.0000	8.2691E-06	.6109
110.00	2.0490E-04	.1512	3.3177E-04	.1478	9.7624E-06	.6025	.0000E+00	.0000	9.8691E-06	.5788
120.00	2.1226E-04	.1774	2.5610E-04	.1897	8.9914E-06	.5112	.0000E+00	.0000	.0000E+00	.0000
140.00	1.7646E-04	.0995	2.3528E-04	.0914	1.8867E-05	.3640	.0000E+00	.0000	2.6264E-06	1.0000
160.00	1.3590E-04	.1051	1.8688E-04	.1018	5.6664E-06	.5005	.0000E+00	.0000	.0000E+00	.0000
180.00	1.4610E-04	.1069	1.7023E-04	.0990	9.8835E-06	.4111	.0000E+00	.0000	3.9995E-06	.7096
200.00	1.1073E-04	.1141	2.4449E-04	.0776	5.6657E-06	.5047	.0000E+00	.0000	.0000E+00	.0000
225.00	1.1214E-04	.1041	2.1292E-04	.0721	1.0880E-05	.3363	.0000E+00	.0000	.0000E+00	.0000
250.00	7.7184E-05	.1231	2.0412E-04	.0737	4.4277E-06	.5009	.0000E+00	.0000	3.2696E-06	.5780
275.00	4.6518E-05	.1581	9.2572E-05	.1086	6.9283E-06	.4086	.0000E+00	.0000	5.3907E-06	.8155
300.00	7.0316E-05	.1355	7.2768E-05	.1314	8.4489E-06	.3538	.0000E+00	.0000	.0000E+00	.0000
325.00	5.3054E-05	.1445	4.4080E-05	.1712	4.2584E-06	.5002	.0000E+00	.0000	.0000E+00	.0000
350.00	5.2722E-05	.1475	4.0007E-05	.1685	3.1634E-06	.5775	.0000E+00	.0000	.0000E+00	.0000
375.00	3.7967E-05	.1725	3.1966E-05	.1868	3.2627E-06	.5776	.0000E+00	.0000	.0000E+00	.0000
400.00	2.8910E-05	.1969	3.6100E-05	.1750	1.1052E-06	1.0000	.0000E+00	.0000	.0000E+00	.0000
450.00	2.3007E-05	.1587	2.2482E-05	.1597	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
500.00	1.8374E-05	.1779	2.3786E-05	.1526	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
550.00	2.5129E-05	.1511	1.2562E-05	.2089	.0000E+00	.0000	.0000E+00	.0000	5.1227E-07	1.0000
600.00	3.2958E-05	.1292	1.4729E-05	.1927	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
650.00	3.9093E-05	.1170	2.1298E-05	.1581	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
700.00	6.6671E-05	.0884	2.6736E-05	.1400	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
750.00	1.9429E-02	.0025	3.3818E-05	.1233	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000
800.00	.0000E+00	.0000	1.2520E-05	.2010	.0000E+00	.0000	.0000E+00	.0000	.0000E+00	.0000

Fig. B-8 Example of an output file of the surface crossing flux spectrum tally.

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particle current by surface tally
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 omni-directional particle current  [/cm**2/source]

no.  1: current at axial surface, z=      .00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   1.2751E+00  .0000  4.6596E-03  .0738  8.3951E-04  .1740   .0000E+00  .0000  2.8011E-04  .3015
   .50 -   2.50   1.2732E-05  .2886  3.3417E-04  .0562  1.4818E-05  .2672   .0000E+00  .0000  4.2294E-06  .5000
  2.50 -   5.00   3.3953E-07 1.0000  6.3145E-05  .0732  3.3953E-07 1.0000   .0000E+00  .0000  3.3636E-07 1.0000
  5.00 -  10.00   8.4883E-08 1.0000  2.0960E-05  .0635   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000
 10.00 -  11.00    .0000E+00  .0000  3.0315E-07 1.0000   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000

no.  2: current at axial surface, z=     5.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   1.0179E+00  .0022  7.6101E-02  .0174  3.0294E-03  .0841   .0000E+00  .0000  1.0179E-03  .1424
   .50 -   2.50   3.1093E-03  .0177  7.8863E-03  .0103  2.4642E-04  .0624   .0000E+00  .0000  8.6929E-05  .1055
  2.50 -   5.00   1.8912E-04  .0412  1.4039E-03  .0141  2.8641E-05  .1043   .0000E+00  .0000  1.0503E-05  .1722
  5.00 -  10.00   6.7901E-06  .1063  2.4796E-04  .0164  2.5017E-06  .1785   .0000E+00  .0000  7.6342E-07  .3142
 10.00 -  11.00    .0000E+00  .0000  1.0610E-05  .1538   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000

no.  3: current at axial surface, z=    10.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   7.6990E-01  .0000  5.9320E-02  .0137  1.8006E-03  .0769   .0000E+00  .0000  6.6176E-04  .1223
   .50 -   2.50   3.0796E-03  .0124  7.7158E-03  .0069  1.7671E-04  .0526   .0000E+00  .0000  5.7217E-05  .0916
  2.50 -   5.00   3.8527E-04  .0208  2.0019E-03  .0080  4.1607E-05  .0639   .0000E+00  .0000  1.1865E-05  .1253
  5.00 -  10.00   3.1385E-05  .0373  4.6449E-04  .0083  4.5961E-06  .0962   .0000E+00  .0000  1.8616E-06  .1516
 10.00 -  11.00   3.0315E-07  .7071  1.6977E-05  .0892   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000

no.  4: current at axial surface, z=    20.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   4.3976E-01  .0000  2.6999E-02  .0145  3.7862E-04  .1154   .0000E+00  .0000  1.5911E-04  .1766
   .50 -   2.50   1.7360E-03  .0118  4.5707E-03  .0062  5.2843E-05  .0680   .0000E+00  .0000  1.4970E-05  .1241
  2.50 -   5.00   4.0943E-04  .0143  1.6393E-03  .0060  1.4765E-05  .0796   .0000E+00  .0000  5.4254E-06  .1330
  5.00 -  10.00   6.5211E-05  .0181  5.4359E-04  .0047  3.7640E-06  .0763   .0000E+00  .0000  9.8403E-07  .1422
 10.00 -  11.00   1.0231E-06  .3685  2.8723E-05  .0523  3.0275E-07  .5000   .0000E+00  .0000   .0000E+00  .0000

no.  5: current at axial surface, z=    30.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   2.5490E-01  .0000  1.0735E-02  .0165  2.3873E-05  .3333   .0000E+00  .0000  6.3662E-06  .7071
   .50 -   2.50   8.3954E-04  .0127  2.3065E-03  .0067  3.3729E-06  .1950   .0000E+00  .0000  1.8508E-06  .2575
  2.50 -   5.00   2.2948E-04  .0144  9.2548E-04  .0059  1.3123E-06  .1766   .0000E+00  .0000  1.0159E-06  .1976
  5.00 -  10.00   4.1237E-05  .0178  3.8258E-04  .0037  3.4323E-07  .1719   .0000E+00  .0000  2.8573E-07  .1832
 10.00 -  11.00   7.3893E-07  .2250  2.3911E-05  .0436   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000

no.  6: current at axial surface, z=    40.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   6.3662E-06  .5000  1.4841E-03  .0324   .0000E+00  .0000   .0000E+00  .0000  1.5915E-06 1.0000
   .50 -   2.50   8.9193E-06  .0857  8.1182E-04  .0078  3.3157E-08 1.0000   .0000E+00  .0000  1.9876E-07  .5272
  2.50 -   5.00   5.7932E-06  .0599  4.0922E-04  .0056  3.1831E-08  .7453   .0000E+00  .0000  3.9131E-07  .2245
  5.00 -  10.00   2.8064E-06  .0430  1.9854E-04  .0025  1.5915E-08  .5270   .0000E+00  .0000  1.5100E-07  .1780
 10.00 -  11.00   1.5158E-07  .3535  1.5622E-05  .0339   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000

no.  7: current at axial surface, z=    60.00 [cm]
radial mesh [cm]        proton              neutron              pion(+)              pion(0)              pion(-)
   .00 -    .50   3.1831E-06  .5000  6.6049E-05  .1097   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000
   .50 -   2.50   8.6209E-07  .1961  5.7925E-05  .0235   .0000E+00  .0000   .0000E+00  .0000  3.3157E-08 1.0000
  2.50 -   5.00   7.3211E-07  .1203  4.8913E-05  .0140   .0000E+00  .0000   .0000E+00  .0000  2.1221E-08  .7071
  5.00 -  10.00   5.4113E-07  .0699  3.5239E-05  .0074   .0000E+00  .0000   .0000E+00  .0000  1.8568E-08  .3779
 10.00 -  11.00   3.7894E-08  .5000  2.8610E-06  .0574   .0000E+00  .0000   .0000E+00  .0000   .0000E+00  .0000
```

Fig. B-9 Example of an output file of the surface crossing current tally.

```
regionwise nuclear yield (or production)  [numbers/source]
------------------------------------------------------------

   1-H  isotope production
reg.        5
  1     .000E+00
  2    1.000E-05
  3     .000E+00
  4     .000E+00
  5     .000E+00
  6     .000E+00
  7     .000E+00

(eliminated)

  82-Pb isotope production
reg.     187        188        189        190        191        192        193        194        195        196        197        198
  1   .000E+00   .000E+00  2.000E-05  6.000E-05  1.800E-04  3.000E-04  4.400E-04  7.395E-04  1.100E-03  1.800E-03  1.660E-03  2.400E-03
  2   .000E+00   .000E+00   .000E+00  3.000E-05  1.100E-04  3.300E-04  3.100E-04  7.300E-04  1.120E-03  1.480E-03  1.710E-03  2.080E-03
  3   .000E+00   .000E+00  5.000E-06  5.500E-05  1.150E-04  2.799E-04  5.949E-04  1.075E-03  1.660E-03  2.270E-03  2.670E-03  3.315E-03
  4  2.500E-06  2.500E-06  1.000E-05  4.250E-05  1.300E-04  2.800E-04  4.900E-04  9.475E-04  1.550E-03  1.973E-03  2.217E-03  2.630E-03
  5   .000E+00  1.250E-06   .000E+00  1.500E-05  5.250E-05  1.463E-04  3.125E-04  6.025E-04  1.020E-03  1.593E-03  1.830E-03  2.313E-03
  6   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  1.250E-06  1.875E-06  6.250E-07  1.250E-06  1.250E-06  7.500E-06
  7   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  3.984E-05  2.000E-05  1.989E-04  1.000E-04  3.595E-04  4.793E-04  7.199E-04
  8   .000E+00   .000E+00   .000E+00   .000E+00  1.000E-05  3.995E-05  5.000E-05  1.597E-04  3.496E-04  5.891E-04  6.198E-04  1.190E-03
  9   .000E+00   .000E+00   .000E+00   .000E+00  3.492E-05  6.995E-05  1.650E-04  2.649E-04  4.847E-04  9.096E-04  1.209E-03  2.029E-03
 10   .000E+00   .000E+00   .000E+00   .000E+00  1.750E-05  2.500E-05  9.250E-05  1.350E-04  2.898E-04  4.348E-04  7.799E-04  1.085E-03
 11   .000E+00   .000E+00  1.250E-06   .000E+00  6.250E-06  1.125E-05  2.375E-05  4.875E-05  1.200E-04  1.874E-04  2.963E-04  4.525E-04
 12   .000E+00   .000E+00   .000E+00  6.250E-07   .000E+00  6.250E-07  5.000E-06  9.997E-06  1.625E-05  3.188E-05  6.063E-05  1.188E-04
 13   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  1.957E-05  2.000E-05  3.959E-05  6.000E-05  8.000E-05  1.598E-04  2.800E-04
 14   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  4.000E-05  5.975E-05  1.399E-04  2.700E-04  4.000E-04  6.998E-04
 15   .000E+00   .000E+00   .000E+00  1.000E-05  5.000E-06  3.500E-05  9.495E-05  2.347E-04  3.497E-04  6.747E-04  9.094E-04  1.610E-03
 16   .000E+00   .000E+00  2.500E-06  2.500E-06  1.750E-05  3.750E-05  8.750E-05  1.450E-04  2.449E-04  5.050E-04  7.049E-04  1.082E-03
 17   .000E+00   .000E+00   .000E+00  1.250E-06  2.500E-06  6.250E-06  2.125E-05  5.500E-05  9.750E-05  1.713E-04  3.625E-04  4.774E-04
 18   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  1.250E-06  8.125E-06  1.688E-05  3.625E-05  7.250E-05  1.375E-04  2.275E-04
 19   .000E+00   .000E+00   .000E+00   .000E+00   .000E+00  2.000E-05  2.000E-05  1.961E-05  2.000E-05  6.000E-05  6.000E-05  2.397E-04
 20   .000E+00   .000E+00   .000E+00  1.000E-05   .000E+00   .000E+00  1.984E-05  6.987E-05  5.955E-05  2.100E-04  2.496E-04  5.100E-04
 21   .000E+00   .000E+00   .000E+00   .000E+00  5.000E-06  2.493E-05  9.000E-05  1.899E-04  2.948E-04  5.998E-04  1.050E-03  1.625E-03
 22   .000E+00   .000E+00   .000E+00  4.979E-06  1.500E-05  2.995E-05  7.248E-05  1.650E-04  3.349E-04  5.375E-04  8.750E-04  1.510E-03
 23   .000E+00   .000E+00   .000E+00  1.250E-06  3.750E-06  1.500E-05  1.250E-05  5.747E-05  1.450E-04  2.663E-04  4.550E-04  7.513E-04
 24   .000E+00   .000E+00   .000E+00  6.250E-07  3.125E-06  1.188E-05  2.000E-05  5.063E-05  7.875E-05  2.025E-04  3.150E-04  4.819E-04
```

Fig. B-10 Example of an output file of the nuclide yield tally.

82-Pb isotope production

reg.	199	200	201	202	203	204	205	206	207	208
1	2.640E-03	2.960E-03	3.000E-03	4.380E-03	4.380E-03	4.880E-03	6.599E-03	9.099E-03	1.220E-02	1.460E-03
2	2.080E-03	2.330E-03	2.720E-03	3.160E-03	3.640E-03	3.960E-03	5.340E-03	6.810E-03	1.015E-02	1.190E-03
3	3.480E-03	3.855E-03	4.165E-03	4.645E-03	4.585E-03	5.960E-03	7.354E-03	9.264E-03	1.345E-02	1.845E-03
4	2.755E-03	2.987E-03	2.922E-03	3.170E-03	3.220E-03	3.840E-03	4.285E-03	5.092E-03	7.747E-03	9.499E-04
5	2.431E-03	2.485E-03	2.440E-03	2.553E-03	2.431E-03	2.671E-03	2.782E-03	2.986E-03	4.229E-03	8.188E-04
6	6.250E-06	1.188E-05	1.063E-05	1.438E-05	1.938E-05	2.938E-05	3.688E-05	3.938E-05	1.813E-05	1.063E-05
7	1.019E-03	1.620E-03	2.279E-03	3.060E-03	4.459E-03	5.679E-03	9.557E-03	1.484E-02	6.778E-03	1.899E-03
8	1.820E-03	2.300E-03	2.779E-03	3.790E-03	5.179E-03	7.089E-03	1.044E-02	1.572E-02	7.638E-03	2.710E-03
9	2.274E-03	3.334E-03	3.954E-03	5.574E-03	7.230E-03	1.007E-02	1.430E-02	2.101E-02	1.093E-02	3.510E-03
10	1.190E-03	1.737E-03	2.250E-03	2.910E-03	3.610E-03	5.135E-03	6.997E-03	9.979E-03	5.540E-03	1.685E-03
11	6.450E-04	7.425E-04	9.350E-04	1.181E-03	1.497E-03	2.144E-03	2.912E-03	4.049E-03	2.146E-03	7.175E-04
12	1.281E-04	1.931E-04	2.131E-04	3.069E-04	4.131E-04	5.300E-04	6.844E-04	8.981E-04	4.856E-04	1.500E-04
13	5.196E-04	1.079E-03	1.280E-03	1.540E-03	2.959E-03	4.098E-03	5.639E-03	9.659E-03	3.678E-03	1.320E-03
14	1.020E-03	1.650E-03	2.149E-03	3.110E-03	4.029E-03	6.309E-03	9.109E-03	1.371E-02	6.039E-03	2.160E-03
15	2.440E-03	3.124E-03	4.020E-03	5.729E-03	7.394E-03	1.060E-02	1.498E-02	2.152E-02	1.068E-02	3.635E-03
16	1.352E-03	1.932E-03	2.562E-03	3.400E-03	4.310E-03	6.092E-03	8.490E-03	1.226E-02	6.020E-03	2.095E-03
17	6.912E-04	9.463E-04	1.184E-03	1.635E-03	1.969E-03	2.725E-03	4.075E-03	5.625E-03	2.820E-03	9.912E-04
18	2.813E-04	4.188E-04	5.175E-04	7.256E-04	9.300E-04	1.254E-03	1.610E-03	2.021E-03	1.114E-03	3.613E-04
19	4.600E-04	7.800E-04	1.220E-03	1.740E-03	2.440E-03	4.019E-03	5.819E-03	1.050E-02	4.060E-03	1.320E-03
20	8.998E-04	1.350E-03	2.020E-03	3.210E-03	4.689E-03	6.600E-03	1.020E-02	1.611E-02	6.379E-03	2.659E-03
21	2.650E-03	3.595E-03	5.110E-03	7.444E-03	9.588E-03	1.402E-02	2.059E-02	2.975E-02	1.336E-02	4.900E-03
22	1.997E-03	2.995E-03	3.750E-03	5.400E-03	7.032E-03	9.724E-03	1.436E-02	1.989E-02	9.555E-03	3.377E-03
23	1.136E-03	1.707E-03	2.137E-03	3.025E-03	3.822E-03	5.381E-03	7.251E-03	1.001E-02	4.954E-03	1.777E-03
24	6.931E-04	9.675E-04	1.354E-03	1.788E-03	2.245E-03	2.989E-03	3.917E-03	5.422E-03	2.724E-03	9.787E-04

Fig. B-10 Example of an output file of the nuclide yield tally (continued).

```
Summary of energy deposition   [MeV/cm3/source]
---------------------------------------------
particle total = (fission) + (reaction) + (cut-off) + (slow down)
total = (particle total) + (fission fragment) + (recoil of reaction)

reg.    fission     reaction     cut-off    slow down     particle total      fragment     recoil          total
  1   1.6514E-01  3.1776E+00  2.5413E+00  1.5722E+01  2.1606E+01  .0016   7.8699E-01  1.2129E-01  2.2514E+01  .0017
  2   1.1813E-01  2.1600E+00  1.9444E+00  1.2327E+01  1.6550E+01  .0008   5.9638E-01  8.6502E-02  1.7233E+01  .0010
  3   4.9674E-02  1.1617E+00  1.1395E+00  7.4833E+00  9.8342E+00  .0003   3.1396E-01  5.0249E-02  1.0198E+01  .0005
  4   8.9698E-03  4.1914E-01  4.5339E-01  4.8967E+00  5.7782E+00  .0003   9.9011E-02  2.1311E-02  5.8985E+00  .0004
  5   3.6234E-04  8.8753E-02  4.7813E+00  1.1715E-01  4.9876E+00  .0002   1.1629E-02  6.3849E-03  5.0056E+00  .0002
  6   8.0576E-07  6.9171E-05  2.5109E-04  1.1263E-04  4.3369E-04  .0700   1.6985E-05  7.1444E-06  4.5782E-04  .0681
  7   3.1261E-05  3.2389E-03  6.7341E-02  4.5758E-02  1.1637E-01  .0111   3.6340E-04  2.4127E-04  1.1697E-01  .0111
  8   1.2022E-04  6.2289E-03  8.0412E-02  6.7595E-02  1.5436E-01  .0068   1.3819E-03  4.0813E-04  1.5615E-01  .0067
  9   9.6343E-05  4.6482E-03  5.5893E-02  4.4404E-02  1.0504E-01  .0039   9.0511E-04  3.1590E-04  1.0626E-01  .0038
 10   2.8962E-05  2.0072E-03  2.5414E-02  2.4577E-02  5.2027E-02  .0040   3.8689E-04  1.5340E-04  5.2567E-02  .0039
 11   2.9812E-06  5.5841E-04  1.5378E-02  5.0643E-03  2.1003E-02  .0054   6.8412E-05  5.1052E-05  2.1123E-02  .0054
 12   5.5902E-07  6.6497E-05  2.4563E-04  3.7837E-05  3.5052E-04  .0176   1.1595E-05  6.2642E-06  3.6838E-04  .0170
 13   1.4382E-06  1.9068E-04  3.7067E-03  2.3846E-03  6.2834E-03  .0277   2.9413E-05  2.6367E-05  6.3392E-03  .0276
 14   6.4945E-06  7.0705E-04  8.3288E-03  7.2628E-03  1.6305E-02  .0125   1.2699E-04  6.3130E-05  1.6495E-02  .0124
 15   1.7183E-05  9.4420E-04  8.1079E-03  8.1716E-03  1.7241E-02  .0062   1.9441E-04  7.4122E-05  1.7509E-02  .0061
 16   9.0722E-06  6.0483E-04  5.5586E-03  5.7646E-03  1.1937E-02  .0056   1.0934E-04  4.8744E-05  1.2095E-02  .0055
 17   3.3828E-06  2.2633E-04  4.1012E-03  7.7183E-04  5.1027E-03  .0067   4.2182E-05  2.0310E-05  5.1652E-03  .0066
 18   6.8746E-07  5.1511E-05  1.8881E-04  2.8425E-05  2.6943E-04  .0115   8.9218E-06  4.5415E-06  2.8289E-04  .0111
 19    .0000E+00  1.9508E-05  2.9125E-04  7.0850E-05  3.8161E-04  .0582   2.4403E-06  4.5244E-06  3.8857E-04  .0573
 20   5.6545E-07  7.4468E-05  9.9343E-04  4.2507E-04  1.4935E-03  .0222   2.0697E-05  1.0621E-05  1.5249E-03  .0219
 21   1.5409E-06  1.5975E-04  1.6842E-03  8.0353E-04  2.6490E-03  .0093   2.1865E-05  1.7005E-05  2.6879E-03  .0092
 22   2.2118E-06  1.5373E-04  1.7076E-03  6.4313E-04  2.5067E-03  .0071   2.6848E-05  1.4419E-05  2.5479E-03  .0070
 23   1.1118E-06  8.8434E-05  9.0113E-04  5.5638E-05  1.0463E-03  .0067   1.3611E-05  8.1813E-06  1.0681E-03  .0066
 24   4.5946E-07  2.9811E-05  1.1259E-04  1.1701E-05  1.5457E-04  .0074   5.3851E-06  2.6221E-06  1.6257E-04  .0072
```

Fig. B-11 Example of an output file of the heat deposition tally.

Appendix C

Source Program for MCNP4A to Read the History File of Cut-off Neutrons Calculated with NMTC/JAERI97.

Fig. C-1 Record and data structure of the cut-off neutron file (on the logical unit 12).

Fig. C-2 Source program list of user-supplied subroutine "source" in MCNP4A to read the history file of cut-off neutrons calculated with NMTC/JAERI97.

Record format: rnd, rnn, (bufr(i),i=1,nd)

Parameter:

rnd the number of flight information data on a record.
< 0, neutron weight is 1.0. The weight information is not stored in 'bufr'-array. Instead, the value of 1.0 is given as the weight in MCNP4A.
> 0, neutrons have different weight, thus weight is stored in 'bufr'-array.

rnn the number of neutrons on a record.

bufr The array having the information data of cut-off neutron; 'bufr'-array consists of many blocks

nd The absolute value of integer parameter 'rnd'.

Structure type (in a block) of 'bufr'-array:

(a)	rn, x, y, z, (e(i), u(i), v(i), w(i), wt(i), i=1,n)	for rnd>0 and rn>0
(b)	rn, x, y, z, (e(i), u(i), v(i), w(i), i=1,n)	for rnd<0 and rn>0
(c)	rn, x, y, z, (e(i), wt(i), i=1,n)	for rnd>0 and rn<0 (isotropic)
(d)	rn, x, y, z, (e(i), i=1,n)	for rnd<0 and rn<0 (isotropic)

Variables stored in 'bufr'-array:

rn the number of neutrons produced on the same coordinate point (x,y,z).
> 0, directional cosine of produced neutron is given in a block.
< 0, neutron angular distribution is isotropic. The directional cosine is given by random sampling in MCNP4A.

x x position of Cartesian coordinate where neutron is generated [cm].

y y position of Cartesian coordinate where neutron is generated [cm].

z z position of Cartesian coordinate where neutron is generated [cm].

e(i) i-th neutron energy on same production coordinate point [MeV].

u(i) directional cosine on x-coordinate of i-th travelling neutron.

v(i) directional cosine on y-coordinate of i-th travelling neutron.

w(i) directional cosine on z-coordinate of i-th travelling neutron.

wt(i) i-th neutron weight.

n absolute value of the integer variable 'rn'.

Fig. C-1 Record and data structure of the cut-off neutron file (on the logical unit 12).

```
      subroutine source
c        dummy subroutine.  aborts job if source subroutine is missing.
c        if nsr=0, subroutine source must be furnished by the user.
c        at entrance, a random set of uuu,vvv,www has been defined.  the
c        following variables must be defined within the subroutine:
c        xxx,yyy,zzz,icl,jsu,erg,wgt,tme and possibly ipt,uuu,vvv,www.
c        subroutine srcdx may also be needed.
c
      implicit double precision (a-h,o-z)
c
c        code name and version number.
      character kod*8,ver*5
      parameter (kod='mcnp',ver='4a')
c

(eliminated)

c -----------------------------------------------------------------------
c
c        rdum(1)  : cylinder radius of source region
c        rdum(2)  : lower z position of cylinder of source region
c        rdum(3)  : upper z position of cylinder of source region
c        idum(1)  : the number of source particles produced in previous
c                   run (in initial run, it must be 0)
c
      real*4 snnmtc(4000),r1nmtc,r2nmtc
      character hzzzz*15
      save snnmtc,r1nmtc,nnnmtc,k1cont,ni,nd,nn,n0,ndmaxm
      data k1cont / 0 /
c
      if (nps.eq.1.or.k1cont.eq.0) then
         open(12,file='nmtc.ncut',form='unformatted',status='old')
         read(12,end=20) r1nmtc,r2nmtc,(snnmtc(i),i=1,nint(abs(r1nmtc)))
         k1cont=1
         ndmaxm=nint(abs(r1nmtc))
         nnnmtc=nint(r2nmtc)
         nn=0
         ni=1
         nd=1
         n0=0
         if (idum(1).gt.0) then
            n=nnnmtc
   90       if (n.gt.idum(1)) then
               n2=n-idum(1)
   95          n1=nint(abs(snnmtc(ni)))
               if (n1.gt.n2) then
                  nnnmtc=n-idum(1)
                  ndmaxm=nint(abs(r1nmtc))
                  n0=n1-n2
```

Fig. C-2 Source program list of user-supplied subroutine "source" in MCNP4A to read the history file of cut-off neutrons calculated with NMTC/JAERI97.

```
                if (snnmtc(ni).gt.0.) then
                   if (r1nmtc.gt.0.) then
                      nd=nd+n0*5+3
                   else
                      nd=nd+n0*4+3
                   endif
                else
                   if (r1nmtc.gt.0.) then
                      nd=nd+n0*2+3
                   else
                      nd=nd+n0+3
                   endif
                endif
                go to 110
             endif
             n2=n2-n1
             if (snnmtc(ni).gt.0.) then
                if (r1nmtc.gt.0.) then
                   nd=nd+n1*5+4
                else
                   nd=nd+n1*4+4
                endif
             else
                if (r1nmtc.gt.0.) then
                   nd=nd+n1*2+4
                else
                   nd=nd+n1+4
                endif
             endif
             ni=nd
             go to 95
          endif
          read(12,end=20) r1nmtc,r2nmtc,
     &                     (snnmtc(i),i=1,nint(abs(r1nmtc)))
          nnnmtc=nint(r2nmtc)
          n=n+nnnmtc
          go to 90
       endif
    endif
100 if (nnnmtc.le.0) then
       if (nd.ne.ndmaxm.and.nd-1.ne.ndmaxm) call expire(1,'source',
     &   'illegal data structure is detected on source file by nmtc.')
       read(12,end=20) r1nmtc,r2nmtc,(snnmtc(i),i=1,nint(abs(r1nmtc)))
       ndmaxm=nint(abs(r1nmtc))
       nnnmtc=nint(r2nmtc)
       nn=0
       ni=1
       nd=1
       n0=0
    endif
110 continue
```

Fig. C-2 Source program list of user-supplied subroutine "source" in MCNP4A to read the history file of cut-off neutrons calculated with NMTC/JAERI97 (continued).

```
c
      n0=n0+1
      if (n0.eq.1) nd=nd+3
      nl=nint(abs(snnmtc(ni)))
      if (snnmtc(ni).gt.0.) then
         xxx=snnmtc(ni+1)
         yyy=snnmtc(ni+2)
         zzz=snnmtc(ni+3)
         erg=snnmtc(nd+1)
         uuu=snnmtc(nd+2)
         vvv=snnmtc(nd+3)
         www=snnmtc(nd+4)
         nd=nd+4
      else
         xxx=snnmtc(ni+1)
         yyy=snnmtc(ni+2)
         zzz=snnmtc(ni+3)
         erg=snnmtc(nd+1)
         nd=nd+1
         call isos
      endif
      if (rlnmtc.gt.0.) then
         wgt=snnmtc(nd+1)
         nd=nd+1
      else
         wgt=1.d+0
      endif
      if (n0.eq.nl) then
         ni=nd+1
         nd=nd+1
         n0=0
      endif
      nn=nn+1
c
      if (erg.le.0.) then
         write(iuo,140) nps,erg,xxx,yyy,zzz
         go to 40
      endif
  140 format(/' message from s.source ..... neutron energy below zero ',
     &  'was detected and it was skiped.'
     &/' nps=',i8,'  energy=',1pe13.6,'  position =(',3e13.5,')')
      if (idum(2).eq.1) then
         write(hzzzz,'(f15.7)') zzz
         if (hzzzz(9:15).eq.'0000000'.or.hzzzz(9:15).eq.'9999999') then
            if (zzz.ge.0.) then
               if (www.ge.0.) then
                  zzz=zzz+zzz*1.d-7
               else
                  zzz=zzz-zzz*1.d-7
               endif
            else
```

Fig. C-2 Source program list of user-supplied subroutine "source" in MCNP4A to read the history file of cut-off neutrons calculated with NMTC/JAERI97 (continued).

```
            if (www.ge.0.) then
             zzz=zzz-zzz*1.d-7
          else
             zzz=zzz+zzz*1.d-7
          endif
      endif
    endif
 endif
 tme=0.d+0
 ipt=1
 jsu=0
 r=xxx**2+yyy**2
 if (r.gt.0.0) then
    r=sqrt(r)
    if (r.ge.rdum(1)) go to 40
 endif
 if (zzz.le.rdum(2).or.zzz.ge.rdum(3)) go to 40
 do 10 i=1,mxa
 icl=i
 call chkcel(icl,2,j)
10 if (j.eq.0) go to 30
 call expire(1,'source','source is not in any cells.')
20 call expire(1,'source',
&      'end-of-file is detected on source file by nmtc.')
30 nnnmtc=nnnmtc-1
 go to 50
c
40 nnnmtc=nnnmtc-1
 go to 100
50 continue
c
 return
 end
```

Fig. C-2 Source program list of user-supplied subroutine "source" in MCNP4A to read the history file of cut-off neutrons calculated with NMTC/JAERI97 (continued).

国際単位系 (SI) と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名　称	記　号
分, 時, 日	min, h, d
度, 分, 秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ \mathrm{eV}=1.60218\times10^{-19}\ \mathrm{J}$

$1\ \mathrm{u}=1.66054\times10^{-27}\ \mathrm{kg}$

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m{\cdot}kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー, 仕事, 熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位, 電圧, 起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ \text{Å}=0.1\ \mathrm{nm}=10^{-10}\ \mathrm{m}$

$1\ \mathrm{b}=100\ \mathrm{fm}^2=10^{-28}\ \mathrm{m}^2$

$1\ \mathrm{bar}=0.1\ \mathrm{MPa}=10^5\ \mathrm{Pa}$

$1\ \mathrm{Gal}=1\ \mathrm{cm/s^2}=10^{-2}\ \mathrm{m/s^2}$

$1\ \mathrm{Ci}=3.7\times10^{10}\ \mathrm{Bq}$

$1\ \mathrm{R}=2.58\times10^{-4}\ \mathrm{C/kg}$

$1\ \mathrm{rad}=1\ \mathrm{cGy}=10^{-2}\ \mathrm{Gy}$

$1\ \mathrm{rem}=1\ \mathrm{cSv}=10^{-2}\ \mathrm{Sv}$

（注）

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および1 uの値はCODATAの1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	$N(=10^5 dyn)$	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　$1\ \mathrm{Pa{\cdot}s}(\mathrm{N{\cdot}s/m^2})=10\ \mathrm{P}$(ポアズ)$(\mathrm{g/(cm{\cdot}s)})$

動粘度　$1\ \mathrm{m^2/s}=10^4\ \mathrm{St}$(ストークス)$(\mathrm{cm^2/s})$

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	$J(=10^7 erg)$	kgf·m	kW・h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J（計量法）

　= 4.184 J　（熱化学）

　= 4.1855 J　(15 °C)

　= 4.1868 J（国際蒸気表）

仕事率　1 PS（仏馬力）

　= 75 kgf·m/s

　= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

AN UPGRADED VERSION OF THE NUCLEON MESON TRANSPORT CODE: NMTC/JAERI97